Exploring the Flavor Structure of Nucleon Sea with Lepton-Pair Production

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BNL Physics Colloquium

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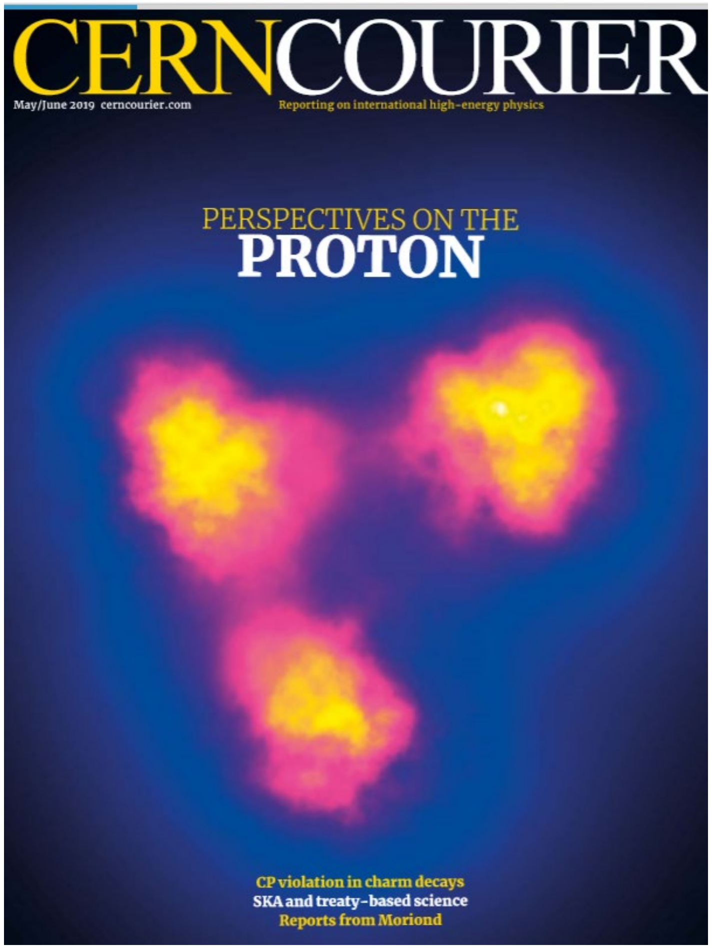
Structures of the nucleons

Why is it interesting?

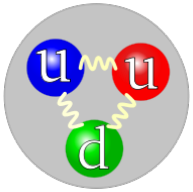


- 99.97% of the visible mass of the Universe is composed of protons and neutrons
- Quantum Chromodynamics (QCD) at the confinement scale remains to be understood

Discovery of proton and neutron

Building blocks of nuclei

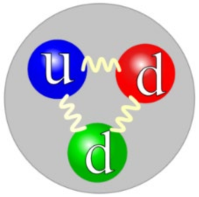
proton



Rutherford

~1919

neutron



Chadwick

1932

Evidences for sub-structure in the nucleons

- Anomalous magnetic moments for proton and neutron
- Excited states of the nucleons
- Quark model description of the nucleons
- Finite size of proton deduced from electron-proton elastic scattering
- Deep-Inelastic Scattering (elastic scattering of electrons off charged quarks)

Magnetic Moments of Leptons and Nucleons

Magnetic moments of charged leptons

$$\mu = \frac{g}{2}\mu_B \qquad \mu_B = \frac{e\hbar}{2m_l}$$

e	μ	τ
$g = 2.00231930436182$	$g = 2.0023318418$	$1.896 < g < 2.026$

Magnetic moments of nucleons

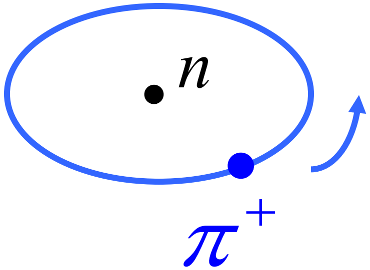
$$\mu = \frac{g}{2}\mu_N \qquad \mu_N = \frac{e\hbar}{2m_p}$$

p	n
$g = 5.58569470$ (expect $g = 2$)	$g = -3.8260854$ (expect $g = 0$)

Early explanation of nucleon anomalous magnetic moments

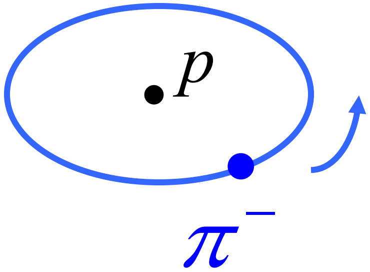
Meson cloud is responsible for the anomalous part ?

$$p \rightarrow n \text{ (point-like)} + \pi^+$$



g_p = 5.59 = 2 + 3.59

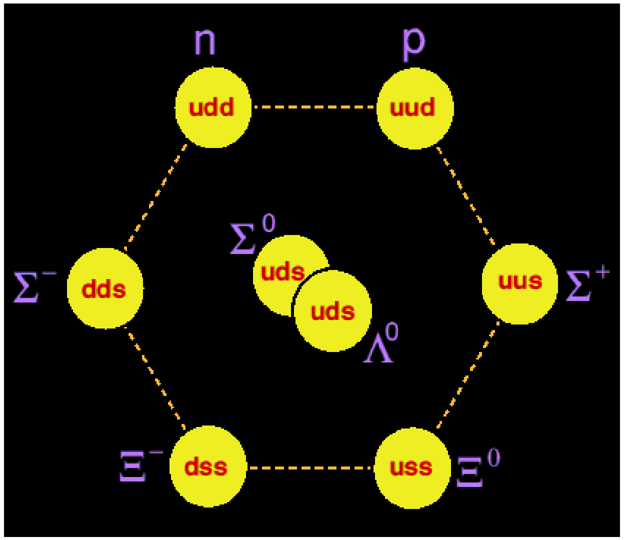
$$n \rightarrow p \text{ (point-like)} + \pi^-$$



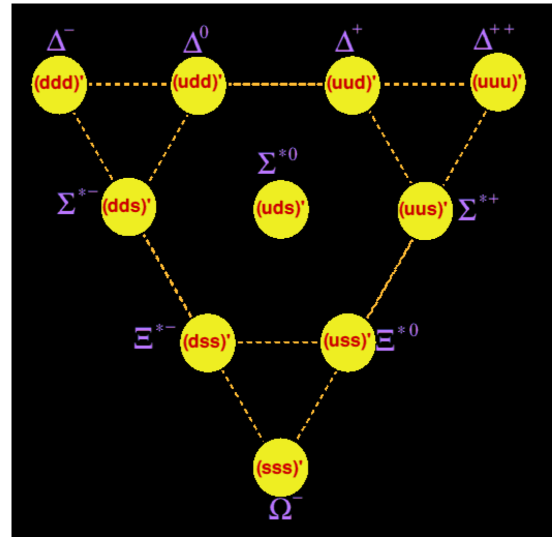
g_n = -3.83 = 0 - 3.83

Quark Model

Octet



Decuplet

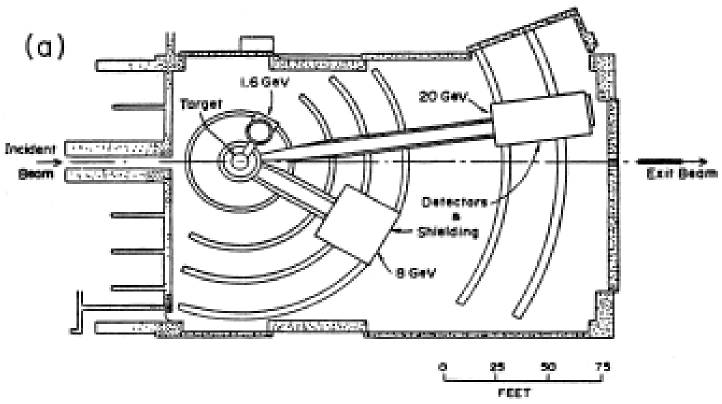


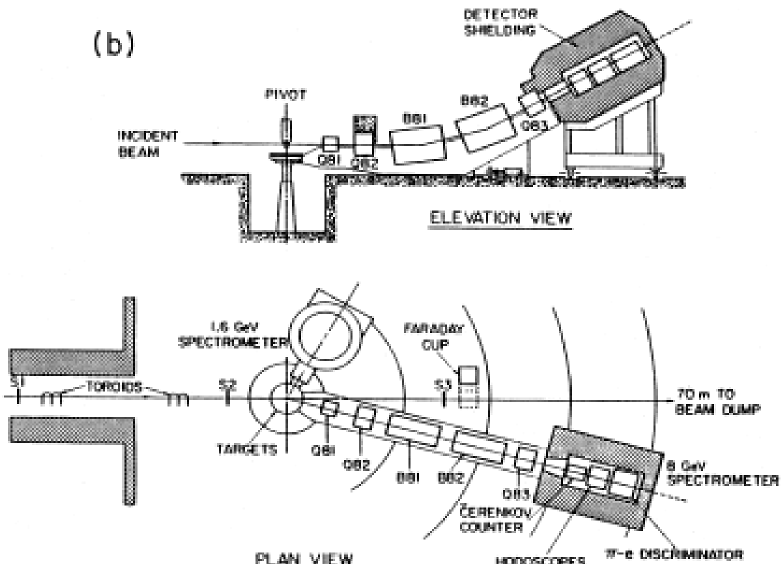
$$p\uparrow = \frac{1}{\sqrt{18}}\left\{\left[2u\uparrow u\uparrow d\downarrow - u\uparrow u\downarrow d\uparrow - u\downarrow u\uparrow d\uparrow\right] + \text{permutations}\right\}$$

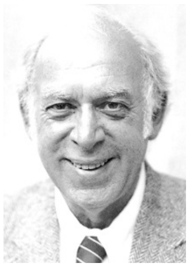
"A search for stable quarks … would help to reassure us of the non-existence of real quarks" (Gell-Mann, 1964)

Observation of scaling behavior in deep-inelastic scattering

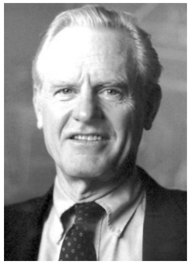
SLAC



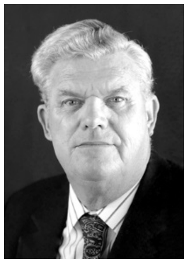




Friedman



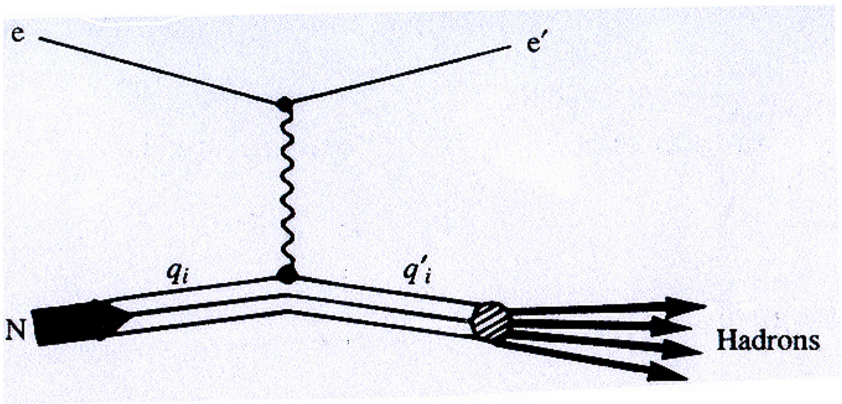
Kendall



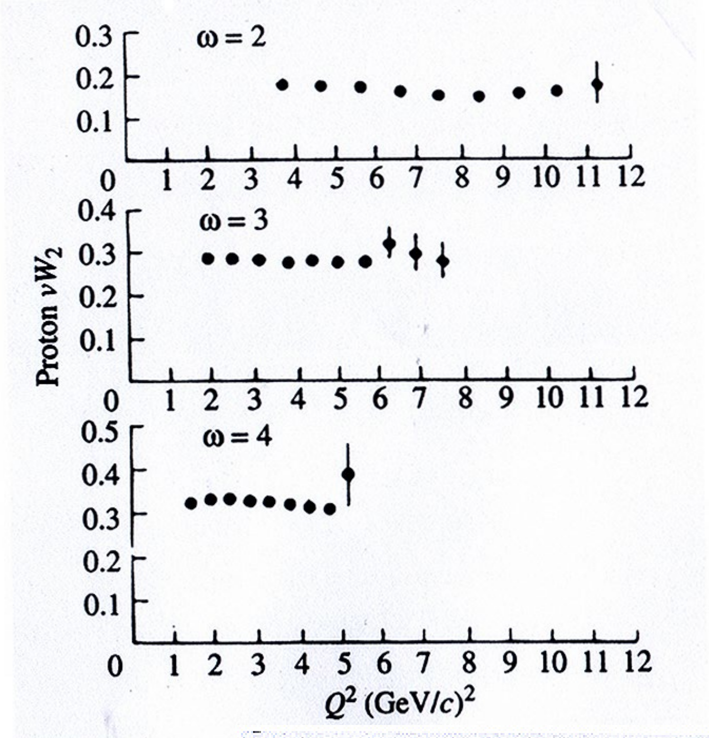
Taylor

e p → e' X

20 GeV electron beam



Observation of scaling behavior in deep-inelastic scattering

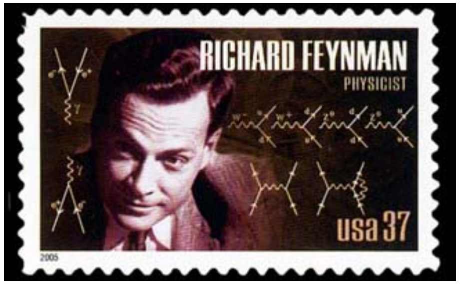


νW_2 is the "form factor" ($F(Q^2)$) for the deep-inelastic scattering, and is found to be independent of Q^2

$$f(r) = \frac{1}{(2\pi)^3}\int F(q^2)e^{-i\vec{q}\cdot\vec{r}/\hbar}d^3q$$

Charge distribution $f(r)$		Form Factor $F(q^2)$	
point	$\delta(r)/4\pi$	1	constant
exponential	$(a^3/8\pi)\cdot\exp(-ar)$	$(1+q^2/a^2\hbar^2)^{-2}$	dipole
Gaussian	$(a^2/2\pi)^{3/2}\cdot\exp(-a^2r^2/2)$	$\exp(-q^2/2a^2\hbar^2)$	Gaussian
homogeneous sphere	$\begin{cases} 3/4\pi R^3 & \text{for } r \le R \\ 0 & \text{for } r > R \end{cases}$	$3\alpha^{-3}(\sin\alpha - \alpha\cos\alpha)$ with $\alpha = \lvert q\rvert R/\hbar$	oscillating

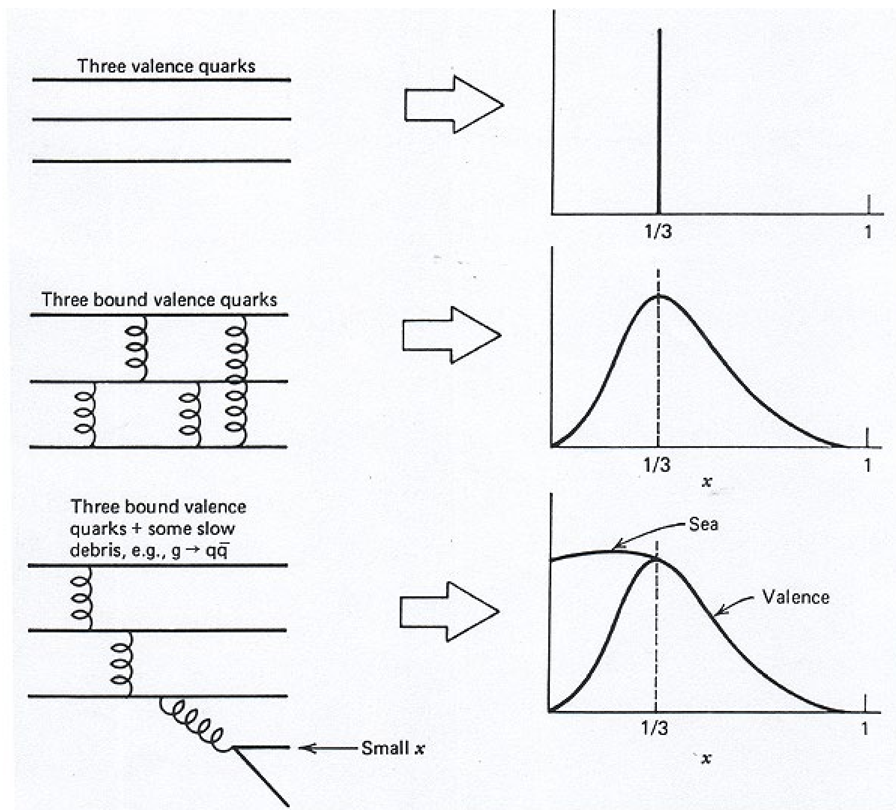
Quark (parton) distributions in the proton



Point-like particle called PARTON by Feynman

If the proton is

Then q(x) is



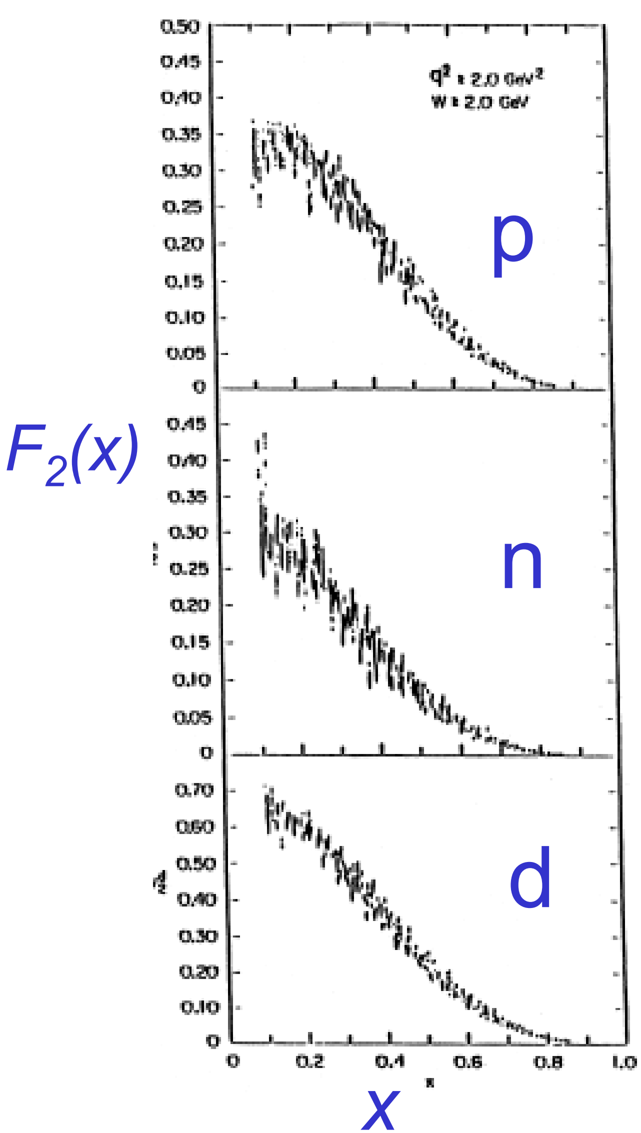
x is the fraction of the proton momentum carried by the quark q $(0 < x < 1)$

Charged partons contain

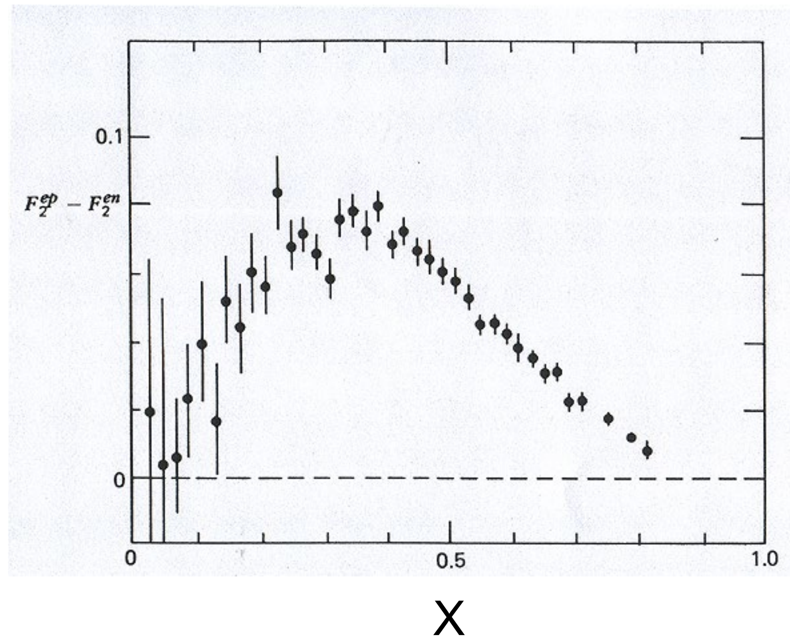
- Valence quarks (u, d)
- Sea quarks and antiquarks $(q, \overline{q})$

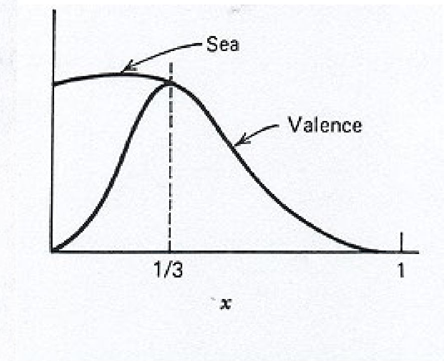
Sea quarks and valence quarks

Sea-quarks at small-x



Valence-quarks from $F_2^p(x)$-$F_2^n(x)$



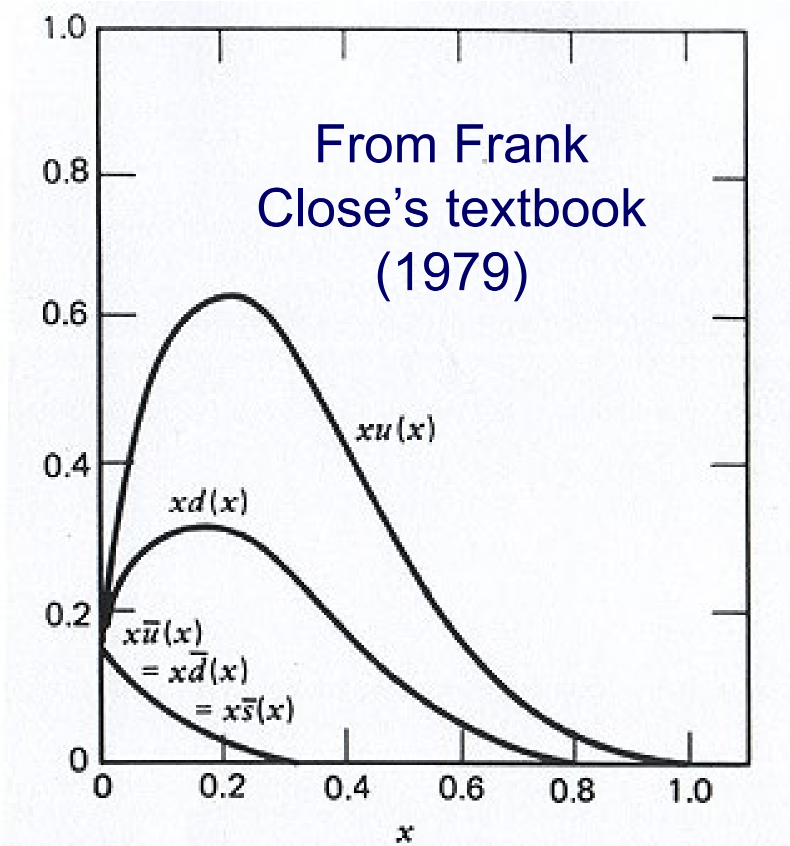


$$F_2^p(x)/x \simeq \frac{4}{9}u(x)+\frac{1}{9}d(x)+\frac{4}{9}\bar{u}(x)+\frac{1}{9}\bar{d}(x)$$

$$F_2^n(x)/x \simeq \frac{4}{9}d(x)+\frac{1}{9}u(x)+\frac{4}{9}\bar{d}(x)+\frac{1}{9}\bar{u}(x)$$

$$[F_2^p(x)-F_2^n(x)]/x \simeq \frac{1}{3}u_V(x)-\frac{1}{3}d_V(x)$$

Flavor structure of the parton distributions in the proton



x is the fraction of the proton momentum carried by the quarks/antiquarks $(0 < x < 1)$

Questions

- *Is* $\bar{u}(x) = \bar{d}(x)$?
- *Is* $\bar{s}(x) = \bar{u}(x)$?
- *Is* $\bar{s}(x) = s(x)$?
- *Is* $\bar{u}_p(x) = \bar{d}_n(x)$?
- *Is* $u_V(x) = 2d_V(x)$?
- *Is* $u_p(x) = d_n(x)$?

Is $\bar{u} = \bar{d}$ in the proton?

Expect $\bar{d} = \bar{u}$ if sea quarks are produced in $g \to q\bar{q}$

<u>Can be tested using the Gottfried Sum Rule</u>

$$I_2^p = \int_0^1 F_2^p(x)/x \, dx = \sum_i (Q_i^p)^2 = 1$$

"Prof. Bjorken and I constructed the sum rules in the hope of destroying the quark model"
(Gottfried, 1967)

Gottfried Sum Rule (modified)

$$S_G = \int_0^1 [(F_2^p(x) - F_2^n(x))/x] dx$$

$$= \frac{1}{3} + \frac{2}{3}\int_0^1 (\bar{u}_p(x) - \bar{d}_p(x)) \, dx$$

$$= \frac{1}{3} \quad (if\ \bar{u}_p = \bar{d}_p)$$

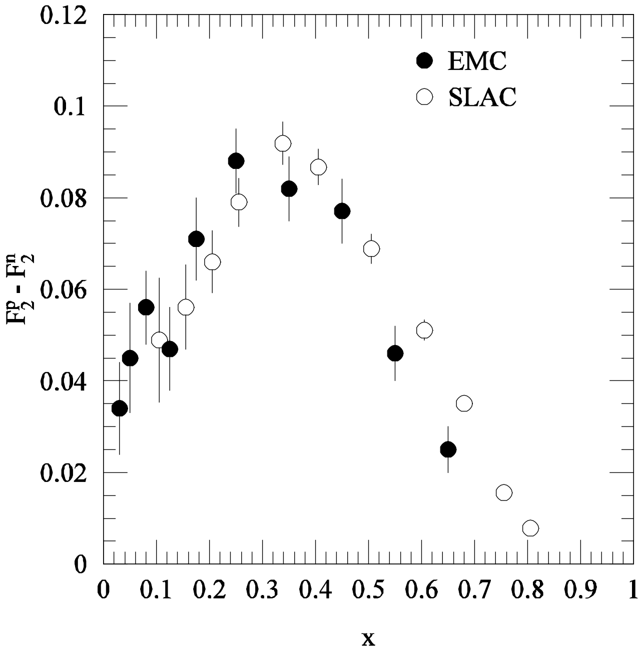
Is $\bar{u} = \bar{d}$ in the proton?

Gottfried Sum-Rule

$$S_G = \int_0^1 [(F_2^p(x) - F_2^n(x))/x]\,dx$$

$$= \frac{1}{3} + \frac{2}{3}\int_0^1 (\bar{u}_p(x) - \bar{d}_p(x))\ dx$$

$$= \frac{1}{3} \quad (if\ \bar{u}_p = \bar{d}_p)$$



S_G = 0.28 (SLAC), S_G = 0.235(EMC) !

suggesting $\bar{d} > \bar{u}$

"The pairs $u\bar{u}$ are suppressed more than $d\bar{d}$ pairs by the exclusion principle"

(Field and Feynman, 1977)

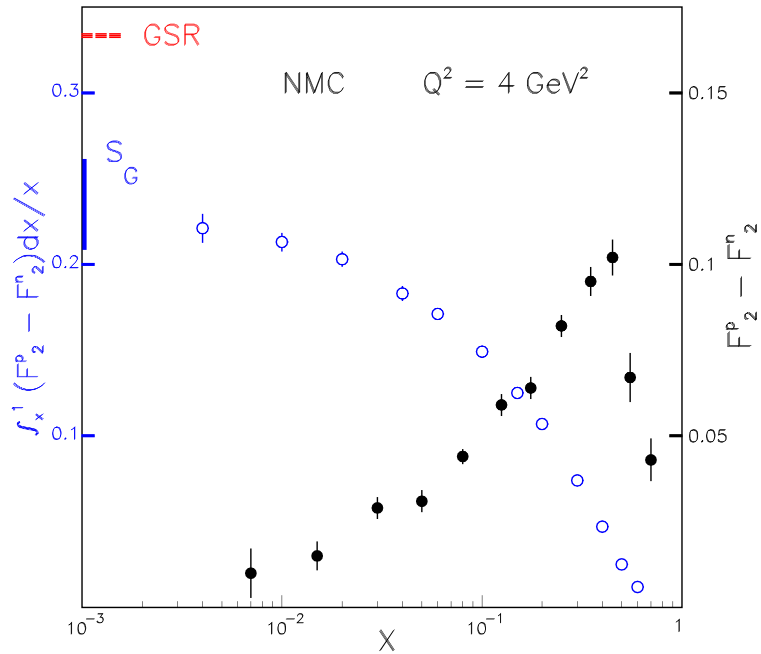
Is $\bar{u} = \bar{d}$ in the proton?

The Gottfried Sum Rule

$$S_G = \int_0^1 [(F_2^p(x) - F_2^n(x))/x]\,dx$$

$$= \frac{1}{3} + \frac{2}{3}\int_0^1 (\bar{u}_p(x) - \bar{d}_p(x))\; dx$$

$$= \frac{1}{3} \quad (if\ \bar{u}_p = \bar{d}_p)$$



New Muon Collaboration (NMC) obtains

$S_G = 0.235 \pm 0.026$ **(Significantly lower than 1/3 !)**

$$\Rightarrow \int_0^1 (\bar{d}(x) - \bar{u}(x))\; dx = 0.148 \pm 0.04$$

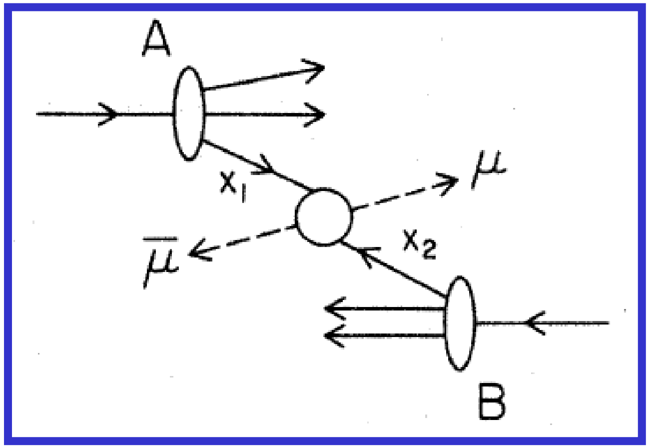
Need independent methods to check the $\bar{d}/\bar{u}$ asymmetry and to measure the x-dependence

The Drell-Yan Process

MASSIVE LEPTON-PAIR PRODUCTION IN HADRON-HADRON COLLISIONS AT HIGH ENERGIES*

Sidney D. Drell and Tung-Mow Yan
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305
(Received 25 May 1970)

On the basis of a parton model studied earlier we consider the production process of large-mass lepton pairs from hadron-hadron inelastic collisions in the limiting region, $s \to \infty$, Q^2/s finite, Q^2 and s being the squared invariant masses of the lepton pair and the two initial hadrons, respectively. General scaling properties and connections with deep inelastic electron scattering are discussed. In particular, a rapidly decreasing cross section as $Q^2/s \to 1$ is predicted as a consequence of the observed rapid falloff of the inelastic scattering structure function νW_2 near threshold.

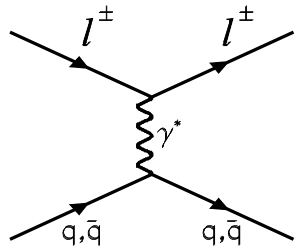


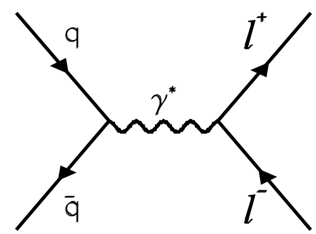
Cited over 1500 times

$$\left(\frac{d^2\sigma}{dx_1 dx_2}\right)_{D.Y.} = \frac{4\pi\alpha^2}{9sx_1x_2}\sum_a e_a^2\left[q_a(x_1)\bar{q}_a(x_2)+\bar{q}_a(x_1)q_a(x_2)\right]$$

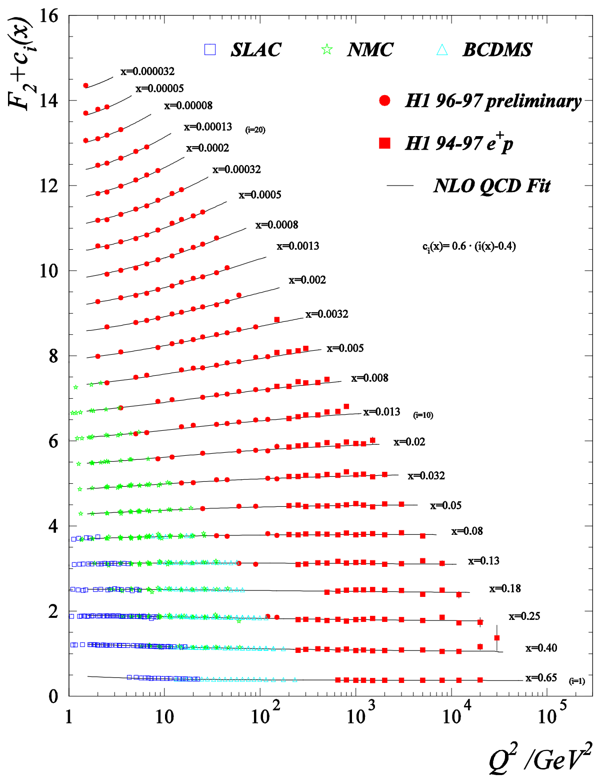
Complimentality between DIS and Drell-Yan

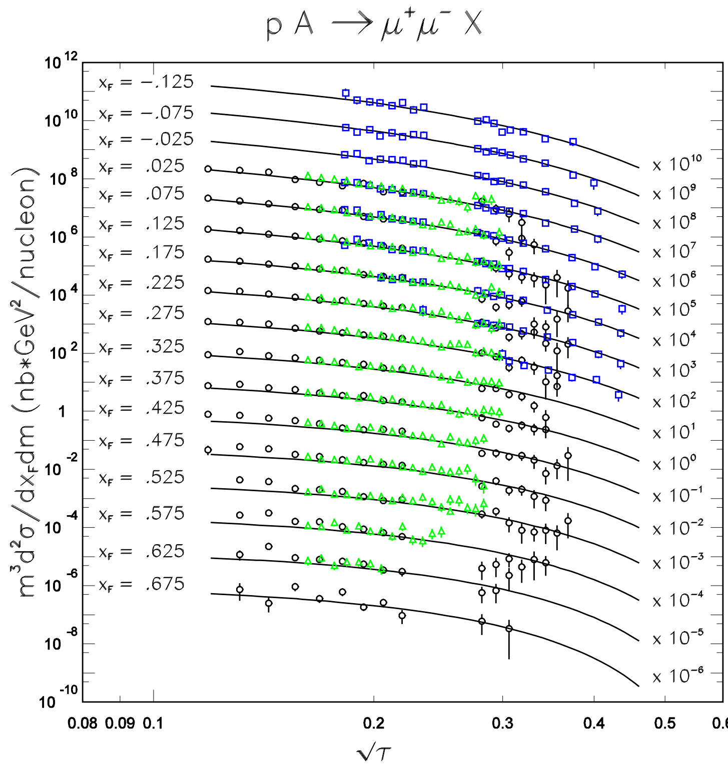
DIS





Drell-Yan





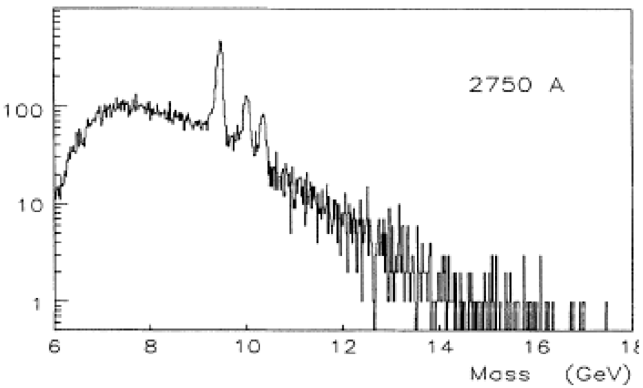
McGaughey, Moss, JCP, Ann.Rev.Nucl. Part. Sci. 49 (1999) 217

Both DIS and Drell-Yan process are tools to probe the quark and antiquark structure in hadrons (factorization, universality)

Lepton-pair production provides unique information on parton distributions

$p + W \rightarrow \mu^+ \mu^- X$

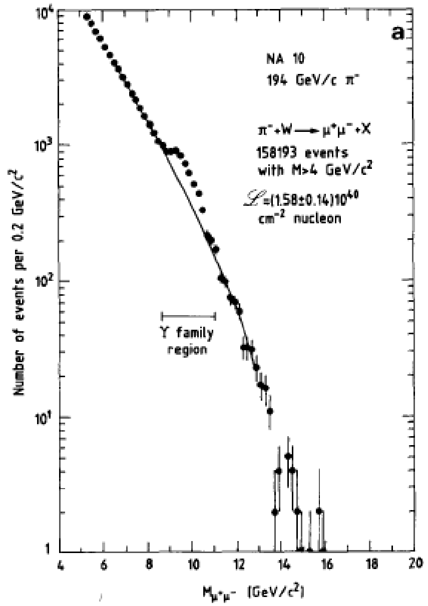
800 GeV/c



Probe antiquark distribution in nucleon

$\pi^- + W \rightarrow \mu^+ \mu^- X$

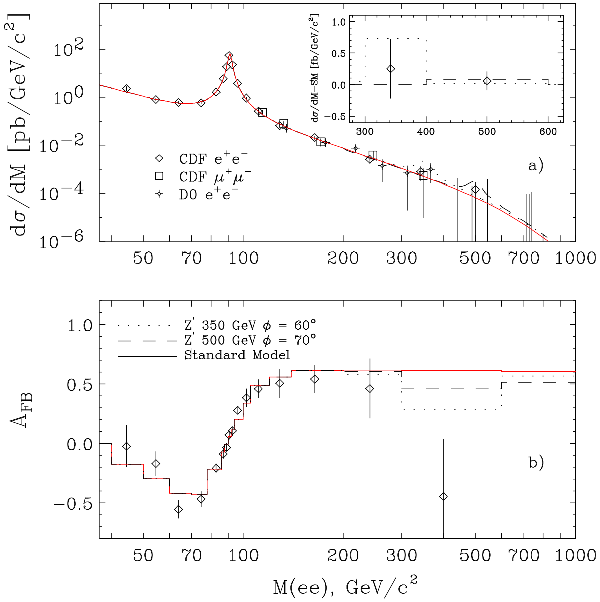
194 GeV/c



Probe antiquark distribution in pion

$\bar{p} + p \rightarrow l^+ l^- X$

1.8 TeV

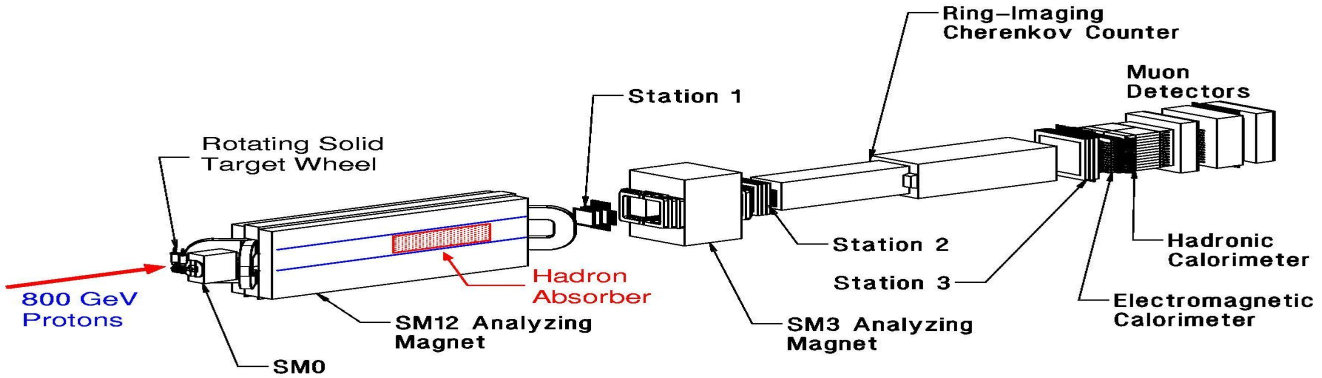


Probe antiquark distributions in antiproton

Unique features of D-Y: antiquarks, unstable hadrons…

Fermilab E605 Dimuon Spectrometer

(E772 / 789 / 866 / 906 /1039)

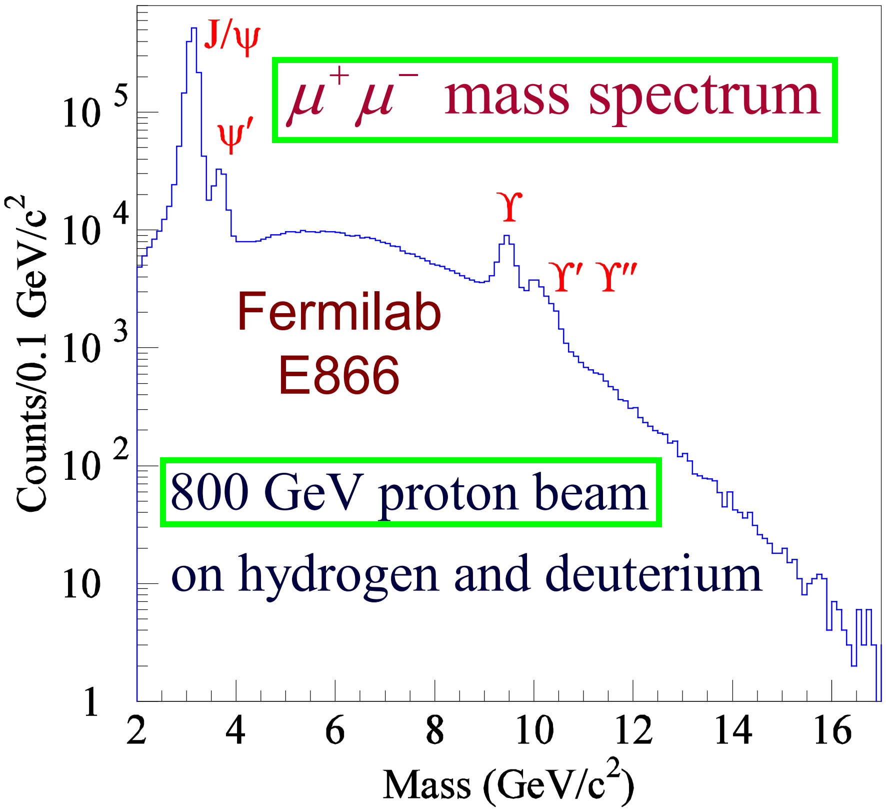


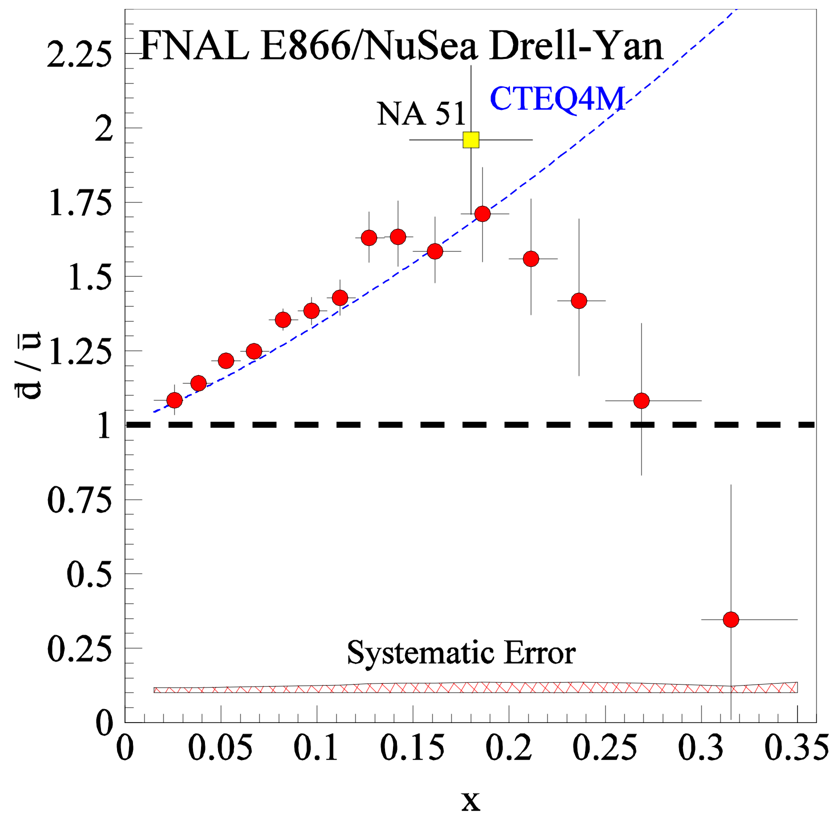
1) Fermilab E772 (proposed in 1986 and completed in 1988)
   "Nuclear Dependence of Drell-Yan and Quarkonium Production"
2) Fermilab E789 (proposed in 1989 and completed in 1991)
   "Search for Two-Body Decays of Heavy Quark Mesons"
3) Fermilab E866 (proposed in 1993 and completed in 1996)
   "Determination of $\bar{d}\,/\,\bar{u}$ Ratio of the Proton via Drell-Yan"
4) Fermilab E906/SeaQuest (proposed in 1999, completed in 7/2017)
   "Drell-Yan with the FNAL Main Injector"
5) Fermilab E1039/SpinQuest (proposed in 2017, beam expected 2021)
   "Drell-Yan with Transversely Polarized Target"

EXPERIMENT E789- Moving Cable at Meson.
"The Snake".

$\bar{d}/\bar{u}$ flavor asymmetry from Drell-Yan

$$\left(\frac{d^2\sigma}{dx_1 dx_2}\right)_{D.Y.} = \frac{4\pi\alpha^2}{9sx_1x_2}\sum_a e_a^2\left[q_a(x_1)\bar{q}_a(x_2) + \bar{q}_a(x_1)q_a(x_2)\right]$$

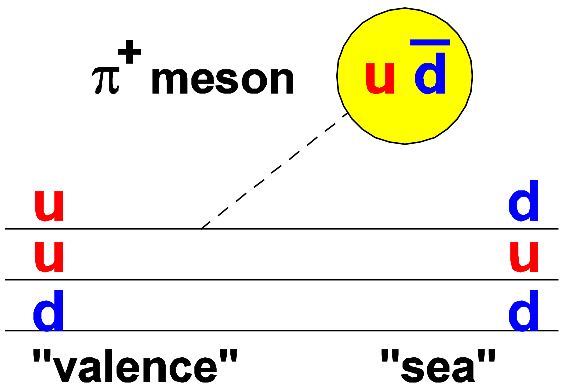




$at\ \ x_1 > x_2:$ Drell-Yan: $\sigma^{pd}/2\sigma^{pp} \sim \frac{1}{2}\left(1 + \bar{d}(x_2)/\bar{u}(x_2)\right)$

Origins of $\bar{u}(x) \neq \bar{d}(x)$?

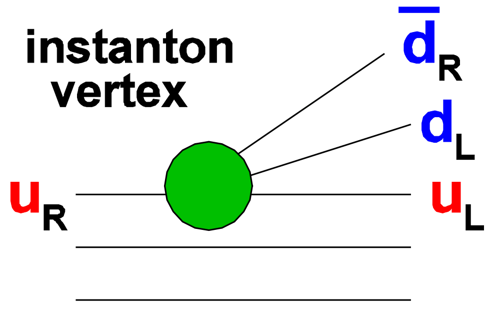
Meson Cloud Models



Chiral-Quark Soliton Model

- nucleon = chiral soliton
- expand in 1/*Nc*
- Quark degrees of freedom in a pion mean-field

Instantons



Theory: Thomas, Miller, Kumano, Ma, Londergan, Henley, Speth, Hwang, Melnitchouk, Liu, Cheng/Li, etc.

(For reviews, see Speth and Thomas (1997), Kumano (hep-ph/9702367), Garvey and Peng (nucl-ex/0109010), Chang and Peng (1406.1260))

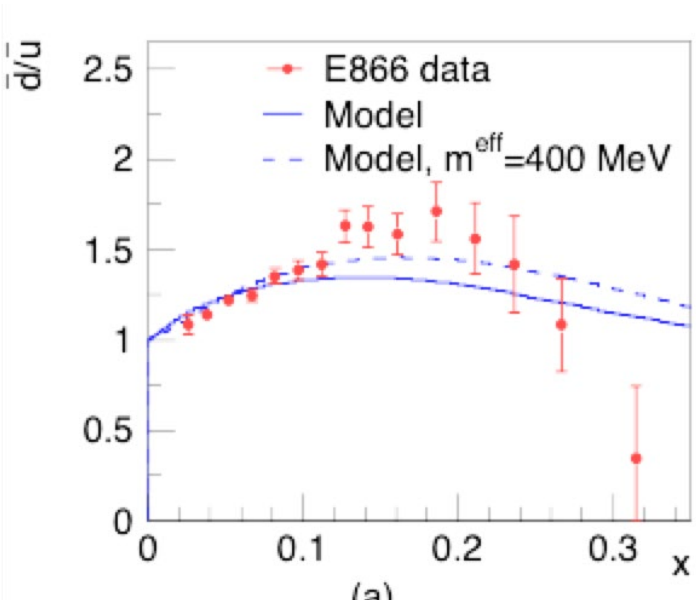
Theses models also have implications on

- asymmetry between $s(x)$ and $\bar{s}(x)$
- flavor structure of the polarized sea

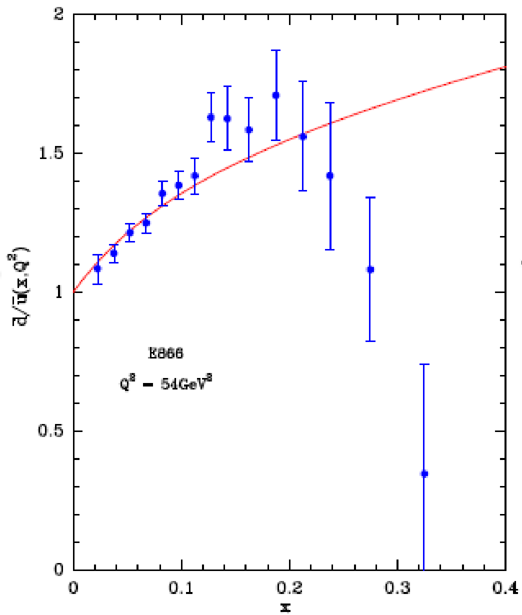
Meson cloud has significant contributions to sea-quark distributions (Sullivan Process)

Origin of asymmetric sea

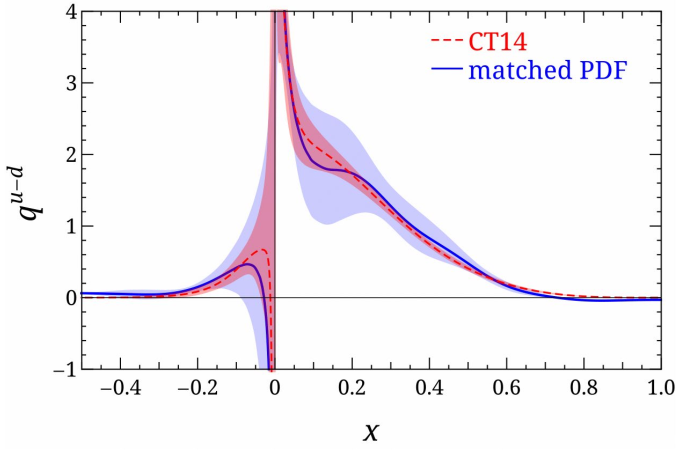
- Several models proposed to explain the origin of asymmetric sea
- Successfully describe the asymmetry at low *x*
- None of these models explains the asymmetry at high *x*



Meson cloud model



Statistical model



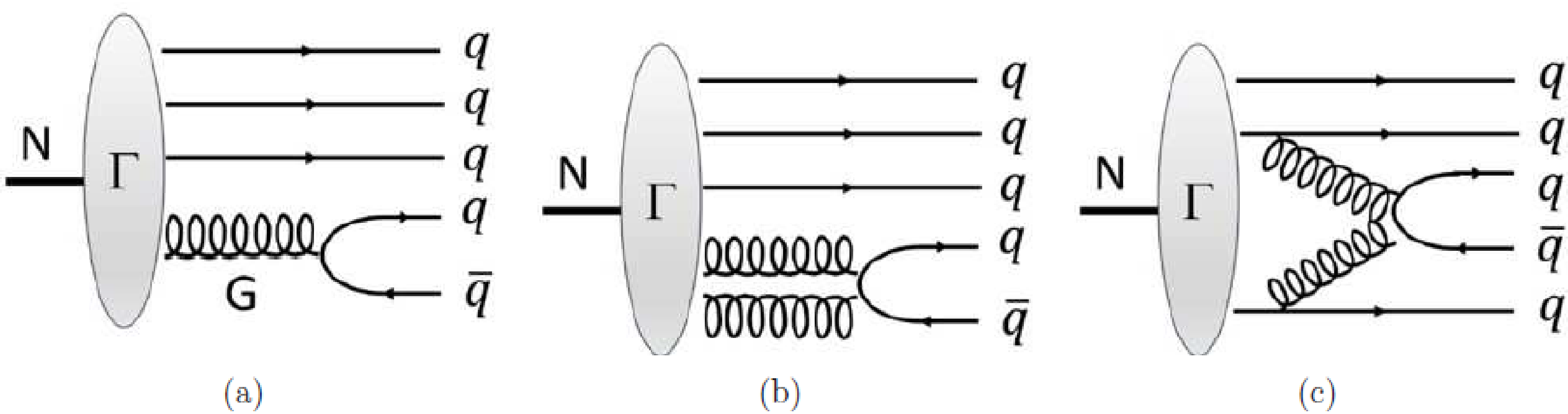
Lattice QCD
LP3 collaboration, arxiv: 1803.04393

Search for the "intrinsic" quark sea

In 1980, Brodsky, Hoyer, Peterson, Sakai (BHPS) suggested the existence of "intrinsic" charm

$$| p\rangle = P_{3q} \, | uud\rangle + P_{5q} \, | uudQ\bar{Q}\rangle + \cdots\cdots$$

The "intrinsic"-charm from $| uudc\bar{c}\rangle$ is "valence"-like and peak at large x unlike the "extrinsic" sea ($g \rightarrow c\bar{c}$)



"extrinsic sea"

"intrinsic sea"

Implications on the "intrinsic" quark sea

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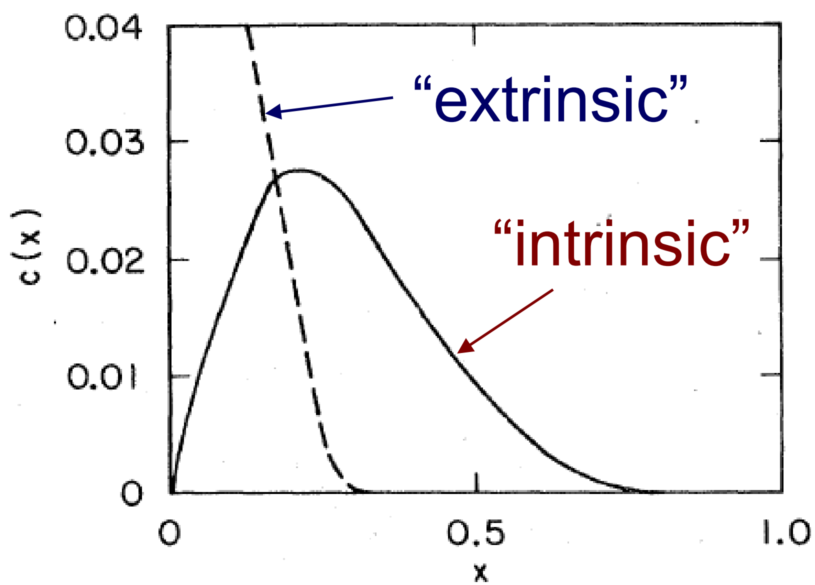


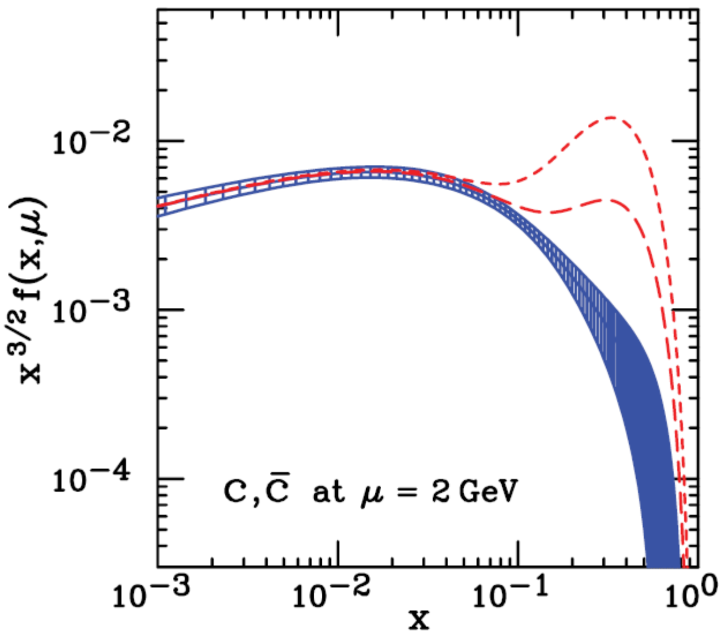
The $| uudc\bar{c}\rangle$ intrinsic-charm can lead to large contribution to charm production at large x

A global fit by CTEQ to extract intrinsic-charm

PHYSICAL REVIEW D 75, 054029 (2007)

Charm parton content of the nucleon

J. Pumplin,[1,*] H. L. Lai,[1,2,3] and W. K. Tung[1,2]



Blue band corresponds to CTEQ6 best fit, including uncertainty

Red curves include intrinsic charm of 1% and 3% (χ^2 changes only slightly)

We find that the range of IC is constrained to be from zero (no IC) to a level 2–3 times larger than previous model estimates. The behaviors of typical charm distributions within this range are described, and their implications for hadron collider phenomenology are briefly discussed.

No conclusive evidence for intrinsic-charm

Search for the lighter "intrinsic" quark sea

$$| p\rangle = P_{3q} \,| uud\rangle + P_{5q} \,| uudQ\bar{Q}\rangle + \cdots\cdots$$

No conclusive experimental evidence
for intrinsic-charm so far

Are there experimental evidences for the intrinsic

$| uudu\bar{u}\rangle, | uudd\bar{d}\rangle, | uuds\bar{s}\rangle$ 5-quark states ?

$$P_{5q} \sim 1/m_Q^2$$

The 5-quark states for lighter
quarks have larger probabilities!

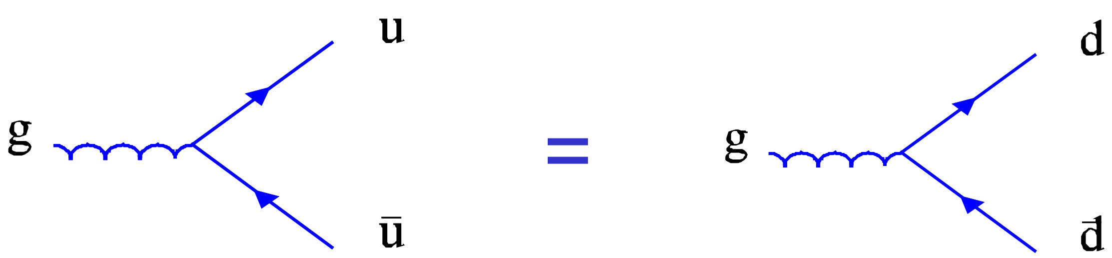
How to separate the "intrinsic sea" from the "extrinsic sea"?

- Select experimental observables which have no contributions from the "extrinsic sea"
- "Intrinsic sea" and "extrinsic sea" are expected to have different x-distributions
  - Intrinsic sea is "valence-like" and is more abundant at larger x
  - Extrinsic sea is more abundant at smaller x

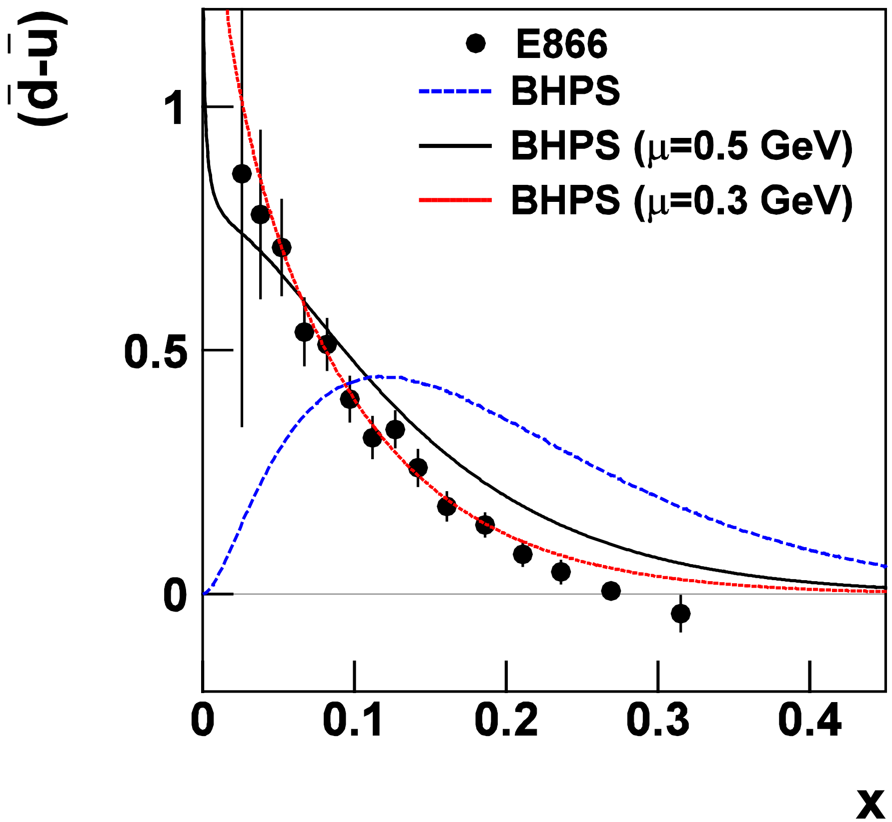
How to separate the "intrinsic sea" from the "extrinsic sea"?

- Select experimental observables which have no contributions from the "extrinsic sea"

$$\bar{d} - \bar{u} \text{ has no contribution from extrinsic sea } (g \to \bar{q} q)$$
$$\text{and is sensitive to "intrinsic sea" only}$$



Comparison between the $\bar{d}(x)-\bar{u}(x)$ data with the intrinsic 5-q model



(W. Chang and JCP , PRL 106, 252002)

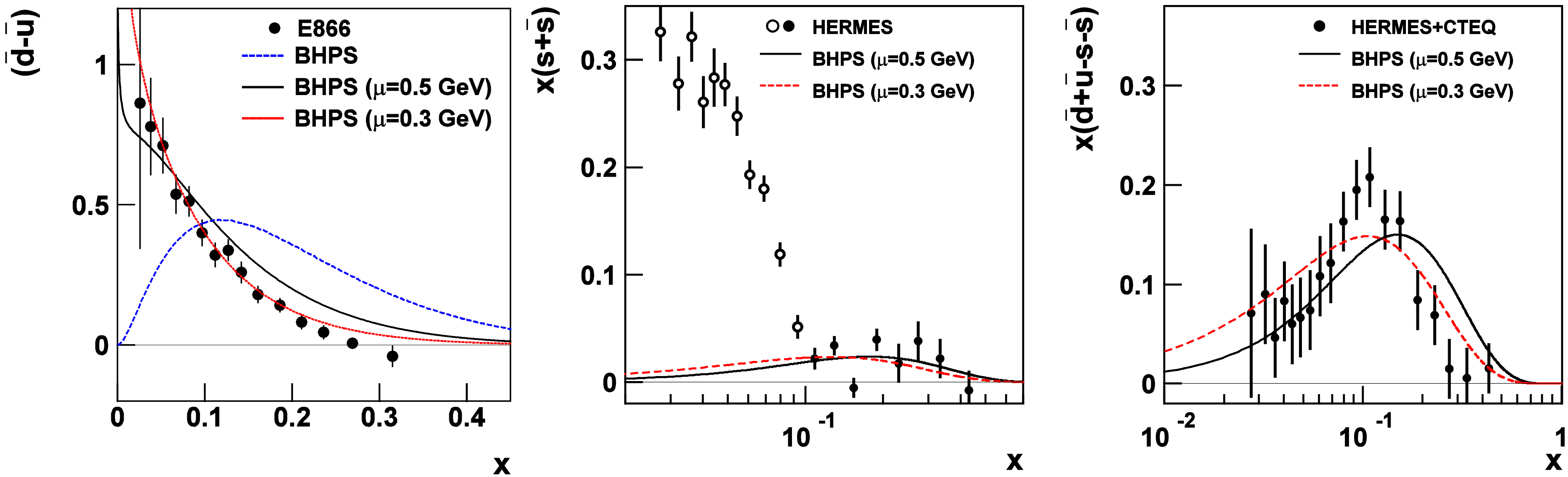
The data are in good agreement with the 5-q model after evolution from the initial scale μ to Q^2=54 GeV^2

The difference in the two 5-quark components can also be determined

$$P_5^{uudd\bar{d}} - P_5^{uudu\bar{u}} = 0.118$$

Extraction of the various light-quark intrinsic-sea components

$\bar{d}(x) - \bar{u}(x)$ $s(x) + \bar{s}(x)$ $\bar{d}(x) + \bar{u}(x) - s(x) - \bar{s}(x)$



$P_5^{uudd\bar{d}} - P_5^{uudu\bar{u}} = 0.118$ $P_5^{uuds\bar{s}} = 0.024$ $P_5^{uudu\bar{u}} + P_5^{uudd\bar{d}} - 2P_5^{uuds\bar{s}} = 0.314$

$$P_5^{uudd\bar{d}} = 0.240; \;\; P_5^{uudu\bar{u}} = 0.122; \;\; P_5^{uuds\bar{s}} = 0.024$$

(W. Chang and JCP, PL B704, 197)

Other Implications

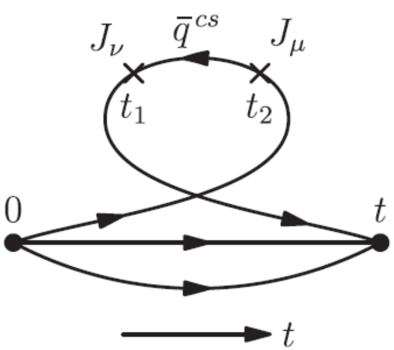
- Search for intrinsic charm and beauty at LHC and EIC.
- Intrinsic gluons in the nucleons?
- Spin-dependent observables of intrinsic sea?
- Connection between the 5-quark model and lattice QCD calculations?
- Intrinsic sea for hyperons and mesons?

Connected-Sea Partons

Keh-Fei Liu,[1] Wen-Chen Chang,[2] Hai-Yang Cheng,[2] and Jen-Chieh Peng[3]
[1]*Department of Physics and Astronomy, University of Kentucky, Lexington, Kentucky 40506, USA*
[2]*Institute of Physics, Academia Sinica, Taipei 11529, Taiwan*
[3]*Department of Physics, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, USA*

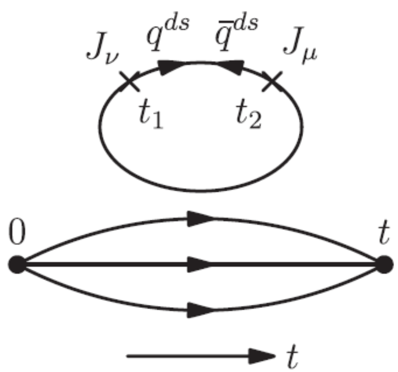
(PRL 109, 252002)

Connected sea



(valence-like)

Disconnected sea



(sea-like)

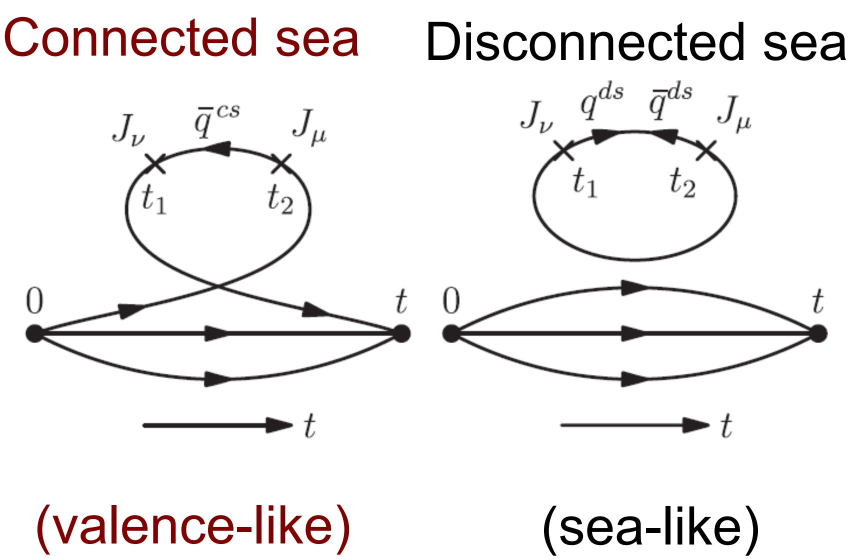
Two sources of sea:
Connected sea (CS) and
Disconnected sea (DS)

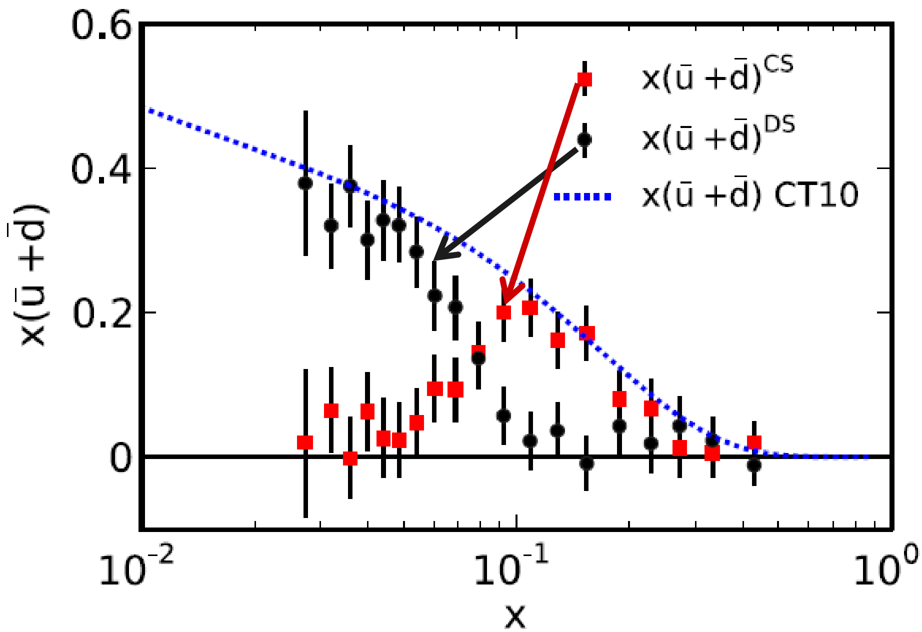
CS and DS have different Bjorken-x and flavor dependences

- x – dependence: at small x, CS $\sim x^{-1/2}$; DS $\sim x^{-1}$
- Flavor dependence: $\bar{u}$ and $\bar{d}$ have both CS and DS; $\bar{s}$ is entirely DS

Connected-Sea Partons

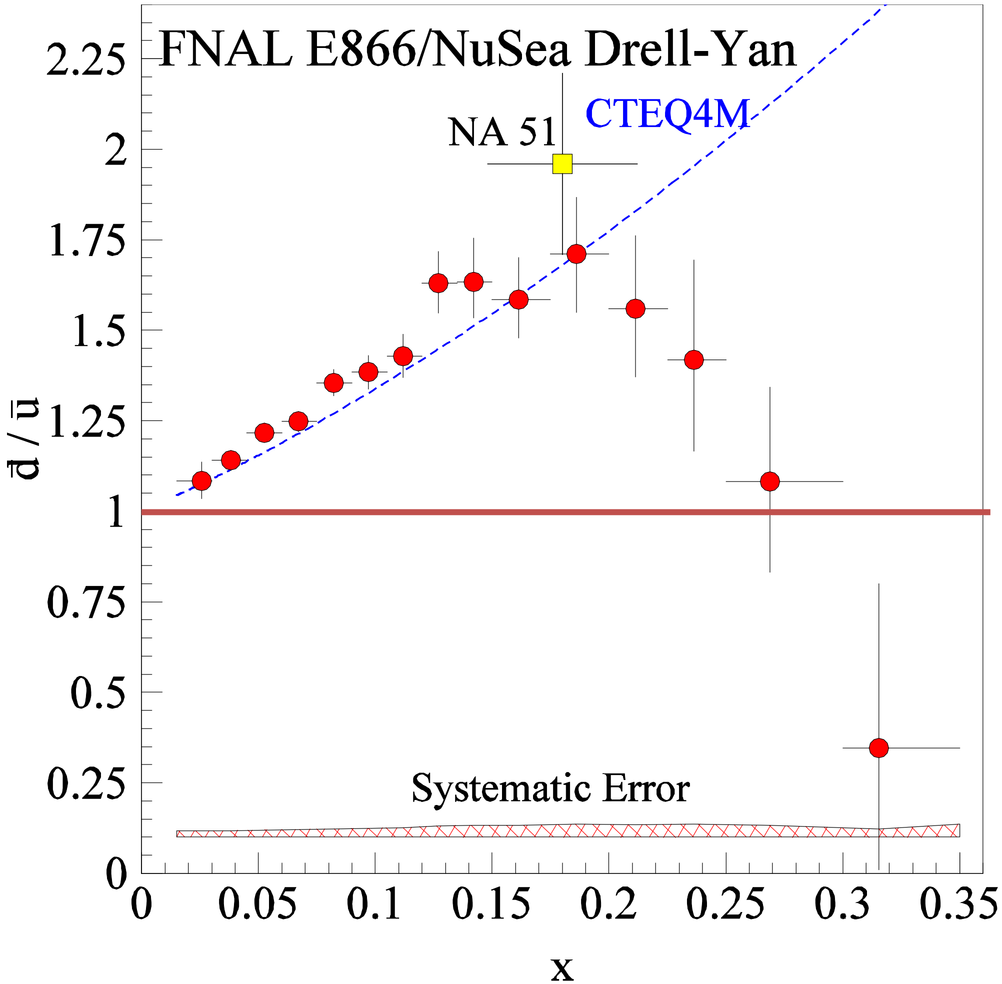
Keh-Fei Liu,[1] Wen-Chen Chang,[2] Hai-Yang Cheng,[2] and Jen-Chieh Peng[3]





- Connected sea component for $\bar{u}(x)+\bar{d}(x)$ is valence-like
- For $\bar{u}+\bar{d}$, momenta carried by CS and DS are roughly equal, at $Q^2=2.5\ \mathrm{GeV}^2$

Does $\bar{d}\,/\,\bar{u}$ drop below 1 at large x?



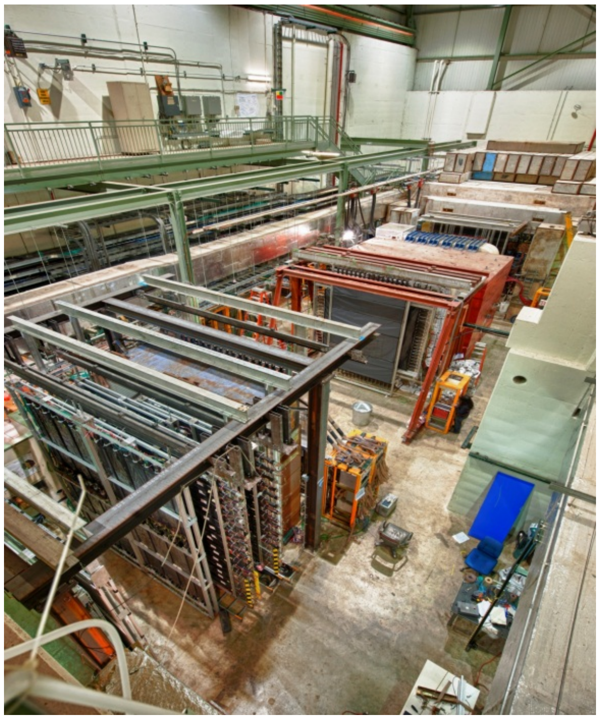
No existing models can explain sign-change

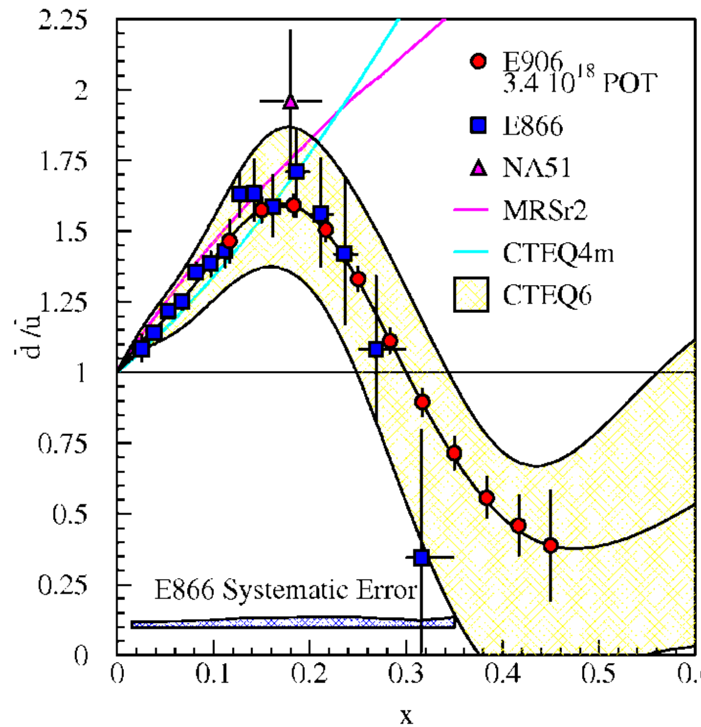
for $\bar{d}(x) - \bar{u}(x)$ at any value of x

Drell-Yan Experiment at Fermilab

SeaQuest Experiment (Unpolarized Drell-Yan using 120 GeV proton beam)

$$\left(\frac{d^2\sigma}{dx_1 dx_2}\right)_{D.Y.} = \frac{4\pi\alpha^2}{9\,s\,x_1 x_2}\sum_a e_a^2\left[q_a(x_1)\bar{q}_a(x_2) + \bar{q}_a(x_1)q_a(x_2)\right]$$

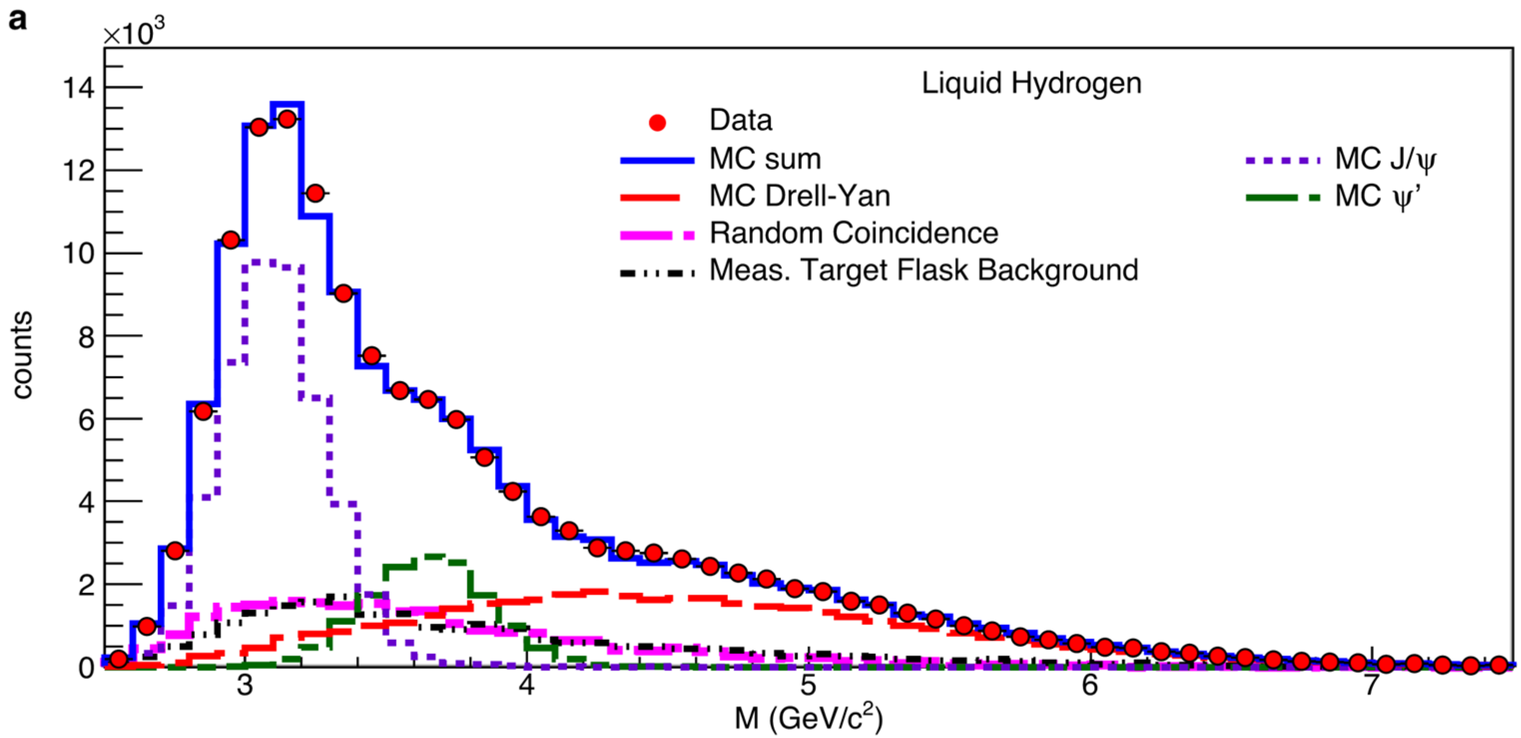




Main goal : Measure $\bar{d}/\bar{u}$ flavor asymmetry up to $x \approx 0.45$

- 2-year production run during 2014-2017

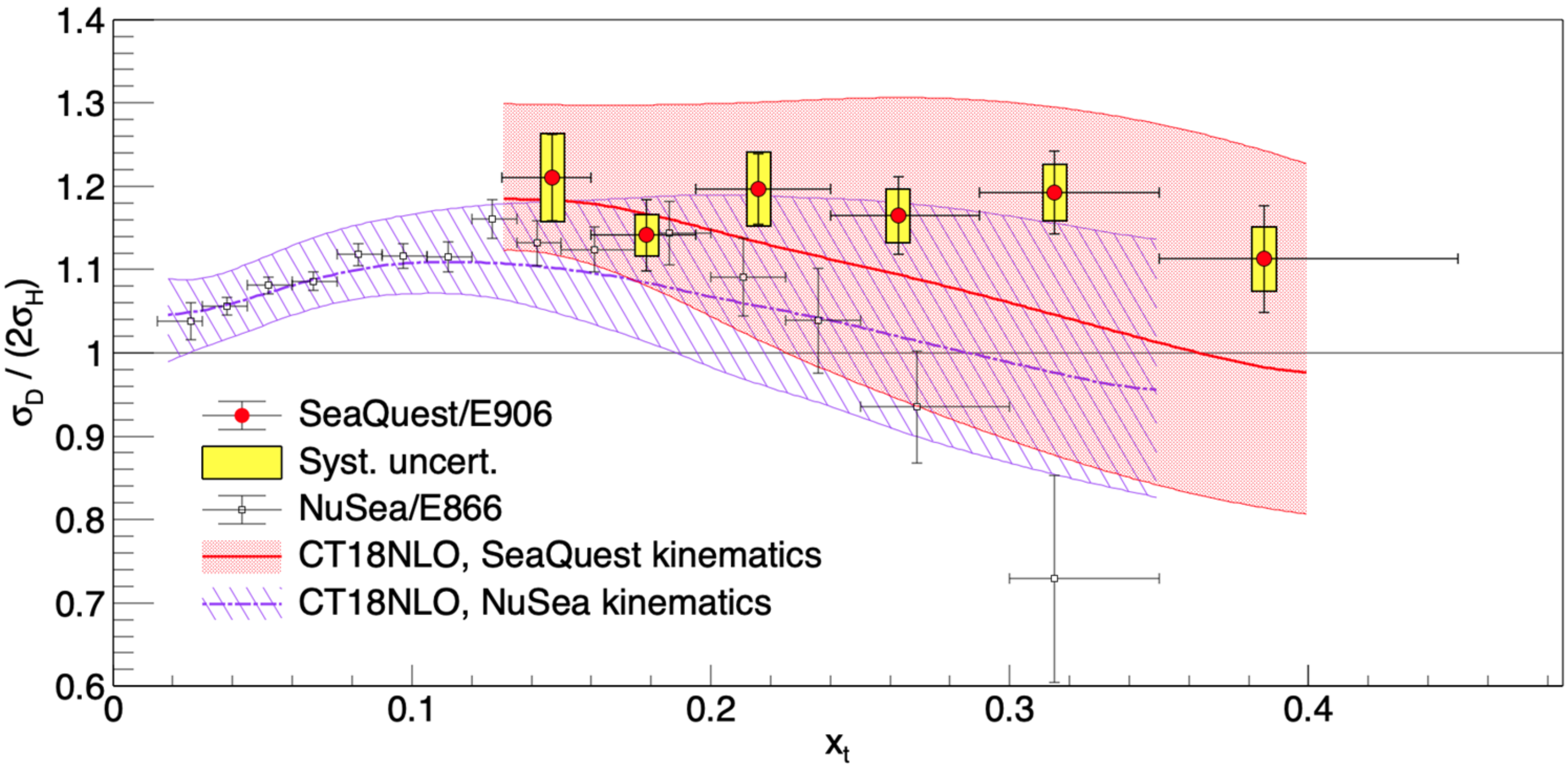
Dimuon mass spectrum from SeaQuest



Nature 590, 561–565 (2021)

- Data taken with LH2, LD2, C, Fe, W
- The data shows the J/Ψ, Ψ' shoulder, and high mass Drell-Yan events

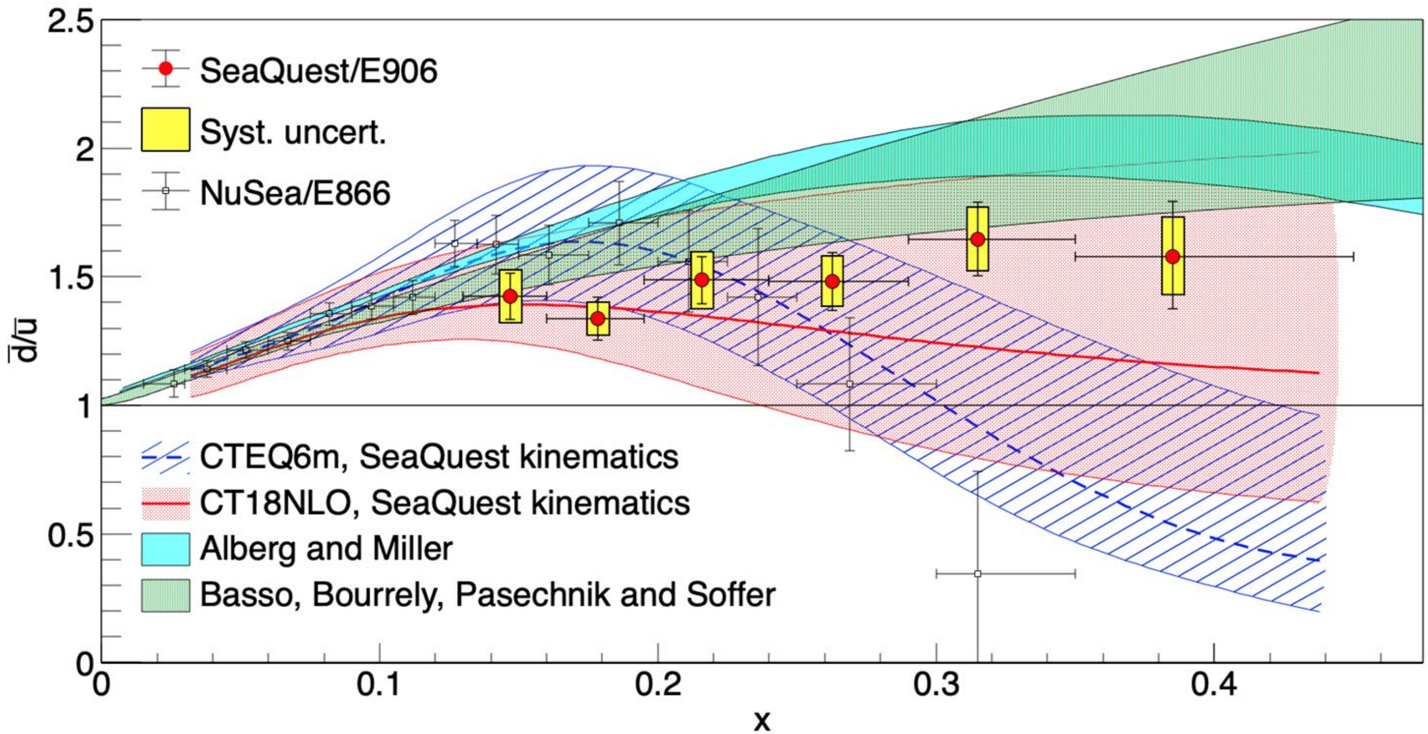
Drell-Yan cross section ratio σpd/2σpp



- New data from SeaQuest shows $\sigma_{pd}/2\sigma_{pp} > 1$ for $0.13 < x < 0.45$
- Difference between E866 (at 800 GeV) and SeaQuest (120 GeV) is partly due to different kinematics coverages

Nature 590, 561–565 (2021)

$\bar{d}/\bar{u}$ result from SeaQuest

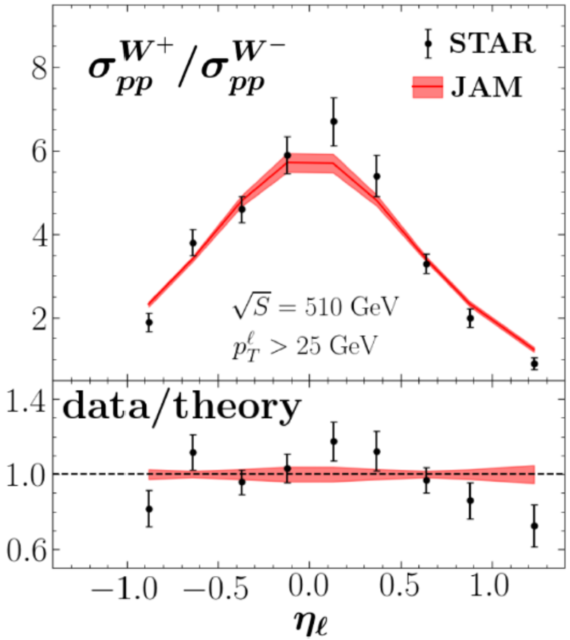


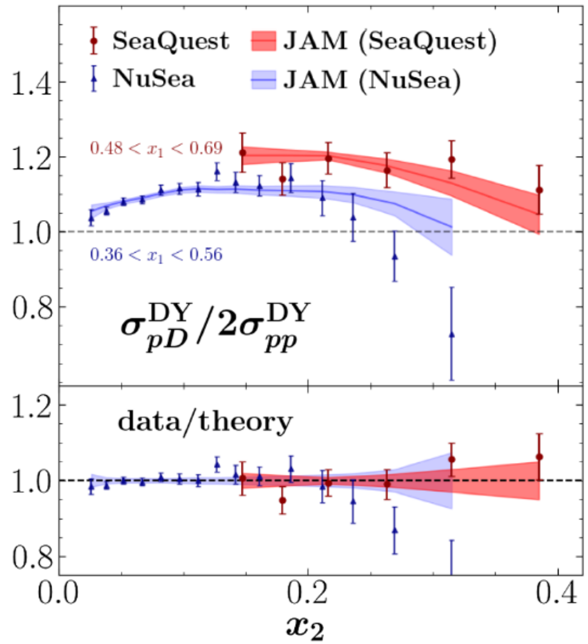
Nature 590, 561–565 (2021)

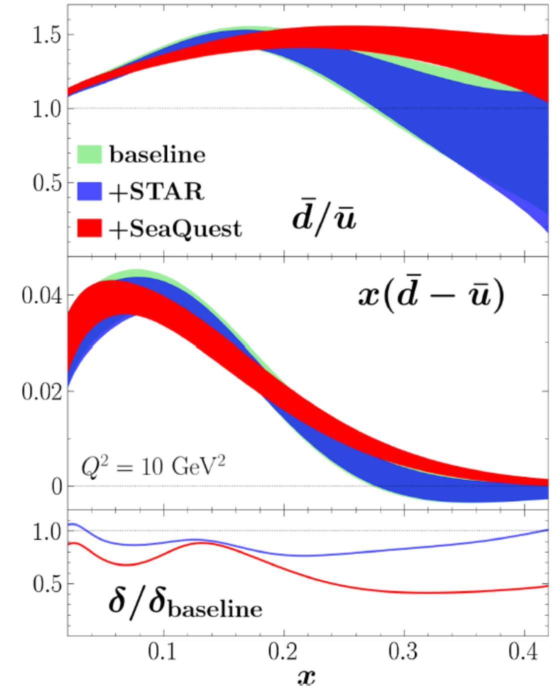
- Observe flavor asymmetry between $\bar{d}(x)$ and $\bar{u}(x)$ for $0.13 < x < 0.45$
- The asymmetry $\bar{d}(x)/\bar{u}(x)$ is found to be greater than 1 for the entire range
- The SeaQuest finding is in agreement with meson-cloud and statistical models
- Results from SeaQuest can put further constraints on parton distribution functions (PDFs)
- Additional SeaQuest data (double the statistics) and other physics topics are being analyzed

Impact on the proton PDFs

JAM, PRD 104, 074031 (2021)







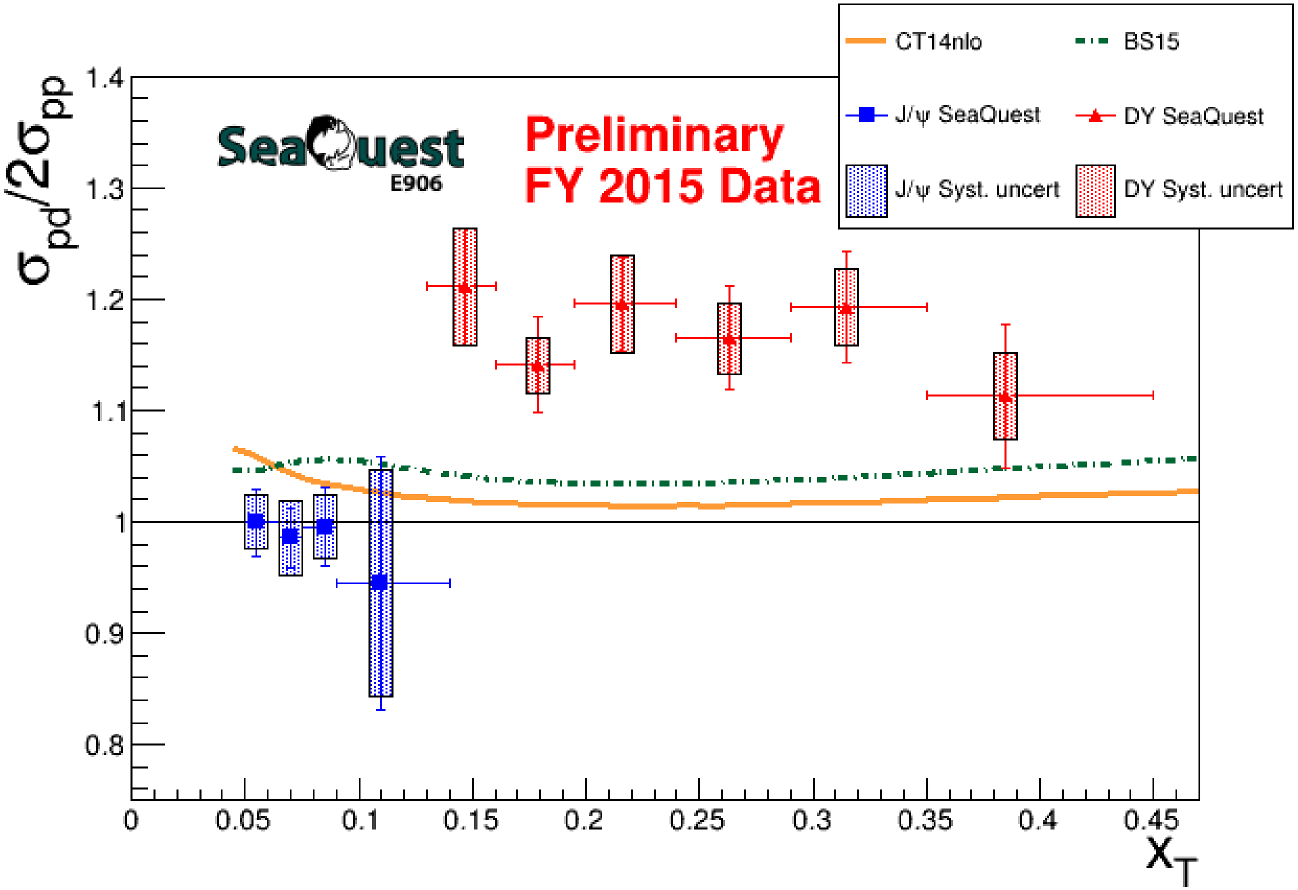
$$\frac{\sigma_{pp}^{W^+}}{\sigma_{pp}^{W^-}} \approx \frac{u(x_1)\bar{d}(x_2) + u(x_2)\bar{d}(x_1)}{d(x_1)\bar{u}(x_2) + d(x_2)\bar{u}(x_1)}$$

$$\left.\frac{\sigma_{pD}^{\rm DY}}{2\sigma_{pp}^{\rm DY}}\right|_{x_1 \gg x_2} \approx \frac{1}{2}\left[1 + \frac{\bar{d}(x_2)}{\bar{u}(x_2)}\right]$$

STAR Data, PRD 103, 012001 (2021)

The STAR W-production data and SeaQuest data signifcantly improve $\bar{d}(x)/\bar{u}(x)$ knowledge

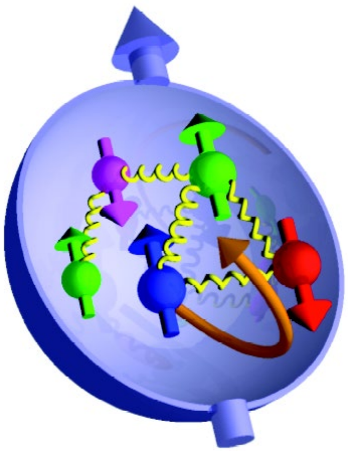
Comparison of $\sigma_{pd}/2\sigma_{pp}$ for Drell-Yan versus J/Ψ

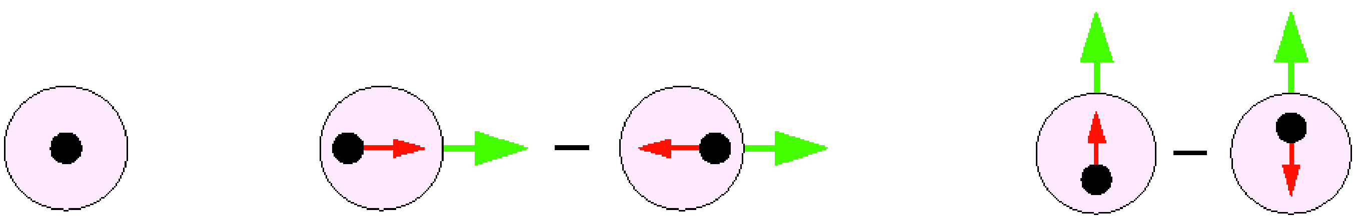


- J/Ψ production is dominated by gluon-gluon fusion process
- J/Ψ ratio should be 1, if gluon content of proton is the same as neutron
- The data show distinct difference for Drell-Yan and J/Ψ cross section ratios

Polarized Drell-Yan with polarized beam/target

- Polarized Drell-Yan experiments are beginning to be studied
- Provide unique information on the quark (antiquark) spin



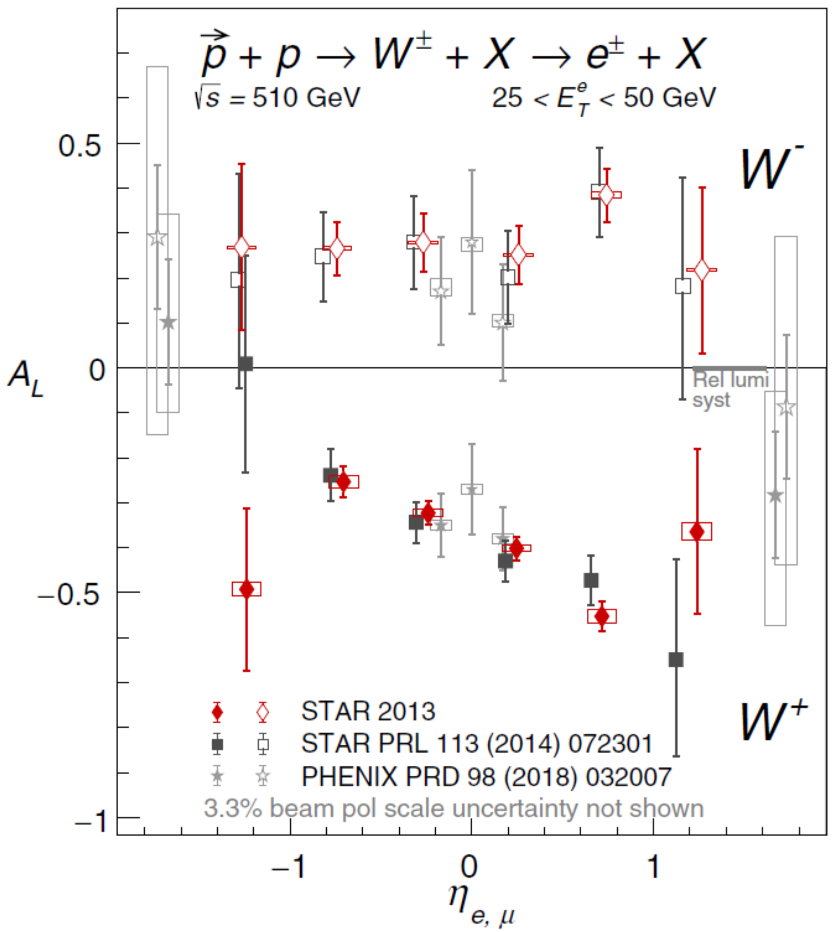


$q(x)$ $\Delta q(x)$ $h_1(x)$

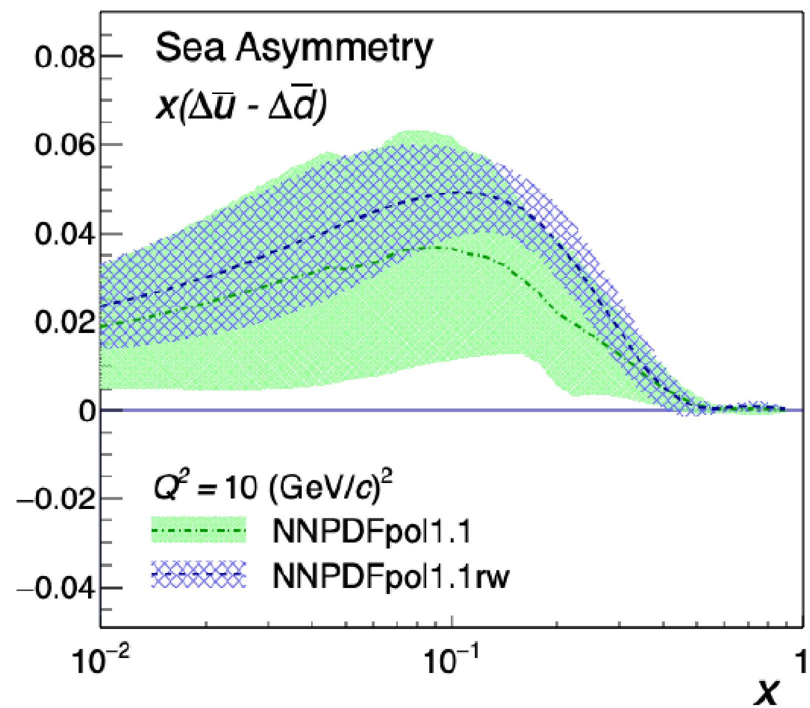
Quark helicity distribution

Quark transversity distribution

$\Delta\bar{u}(x)$ and $\Delta\bar{d}(x)$ from $W^{\pm}$ production at RHIC-spin



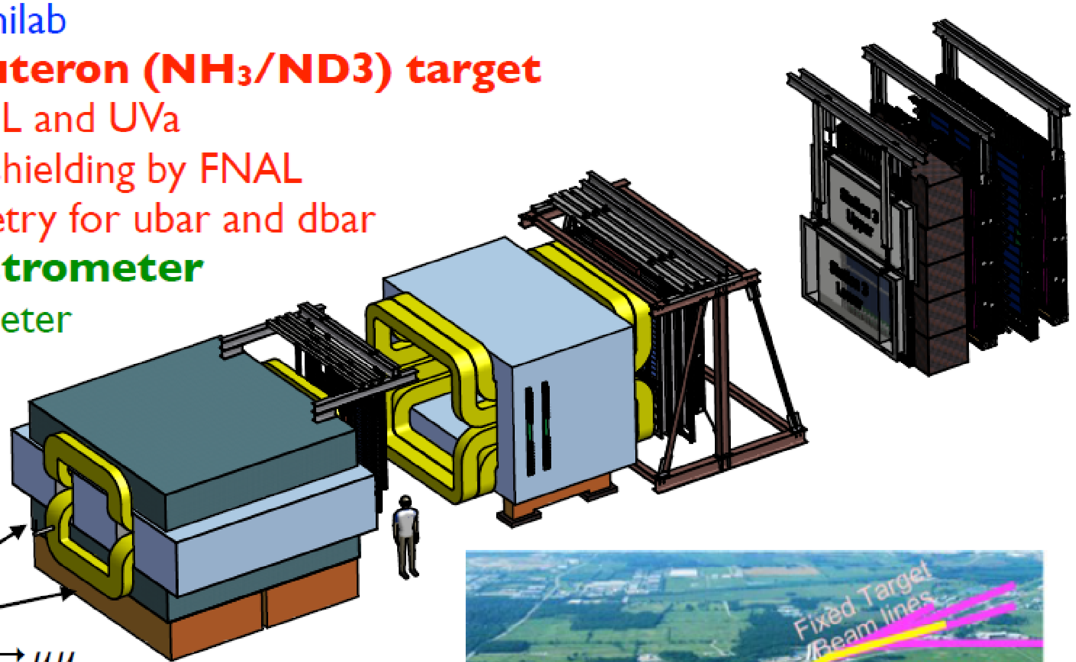
$x\Delta\bar{u}(x) - x\Delta\bar{d}(x)$

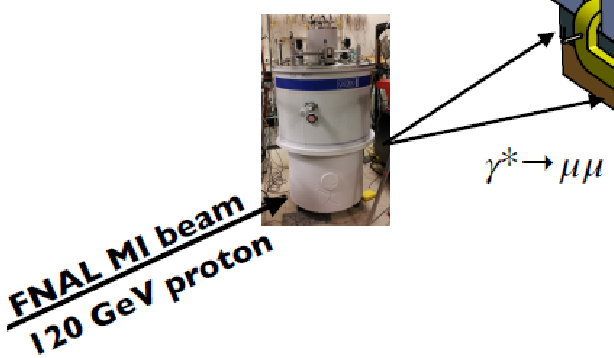


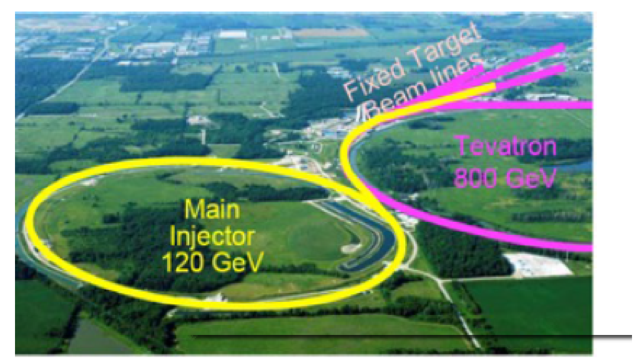
$\Delta\bar{u} > \Delta\bar{d}$ consistent with some models and lattice

Polarized Drell-Yan experiment at Fermilab (E1039) to study sea-quark Sivers function

- **120 GeV proton beam from Main Injector**
  - ➢ Improved focusing
  - ➢ In development at Fermilab
- **Polarized proton/deuteron (NH_3/ND3) target**
  - ➢ In development at LANL and UVa
  - ➢ Modification to target shielding by FNAL
  - ➢ Measure Sivers asymmetry for ubar and dbar
- **Existing dimuon spectrometer**
  - ➢ Existing E906 spectrometer
- **Collaboration**



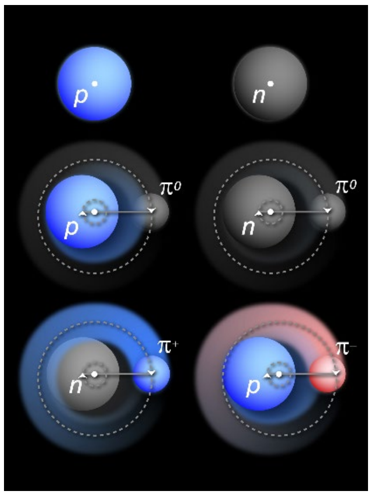




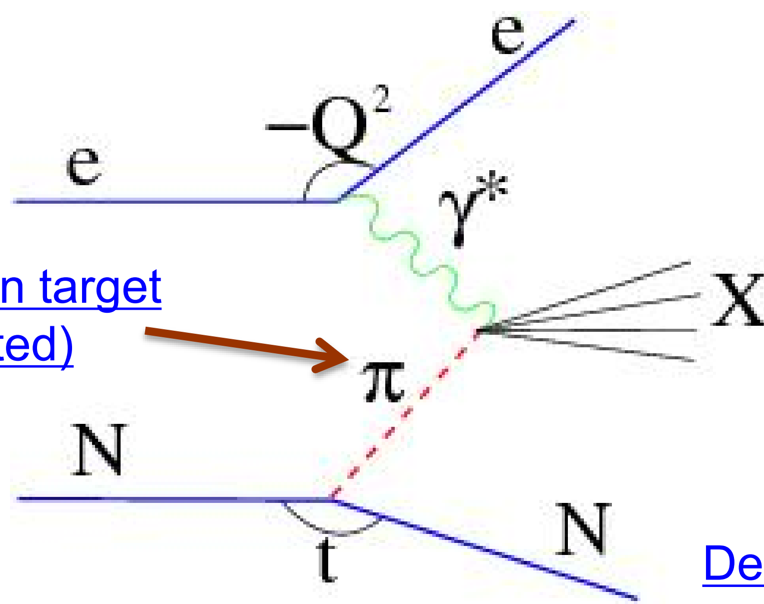
Expected to start data-taking in 2022

Sullivan process – scattering from nucleon-meson fluctuations

(courtesy of Rolf Ent)



Detect scattered electron



Pion/Kaon target (undetected)

DIS event – reconstruct x, Q^2, W^2, also M_X (W_π) of undetected recoiling hadronic system

Detect "tagged" neutron/lambda

$$F_2^{LP(3)} = \sum_i \left[\int_{t_0}^{t_{min}} f_i(z,t)dt \right] F_2^i(x_i, Q^2)$$

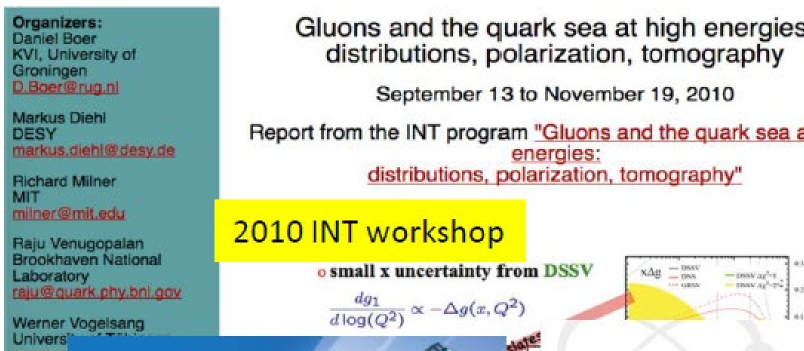
i = π, ρ, …

"Flux factor"

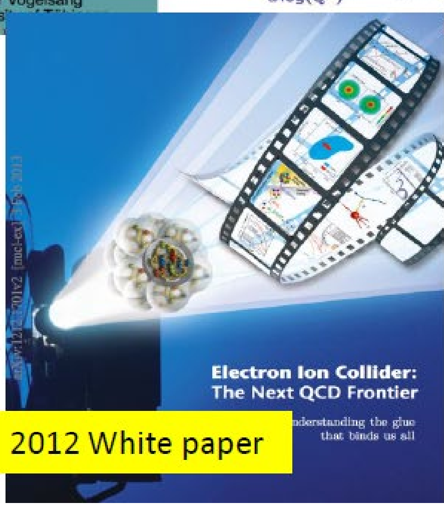
Future Electron-Ion Collider (EIC)

A future (2029~) high-luminosity polarized ep, eA collider dedicated to the study of the nucleon and nucleus structure.

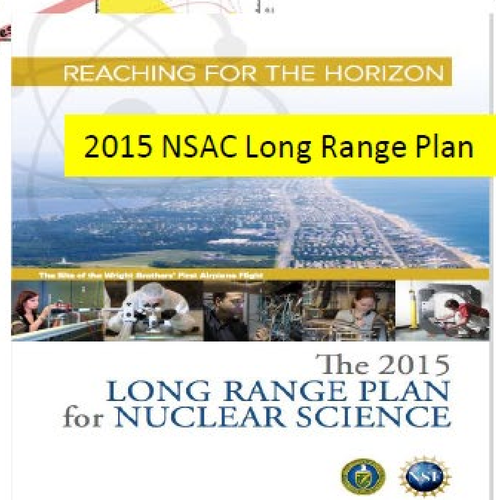
Center-of-mass energy	$20 \lesssim \sqrt{s} \lesssim 140\,\mathrm{GeV}$
Luminosity	$\sim 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$



2010 INT workshop



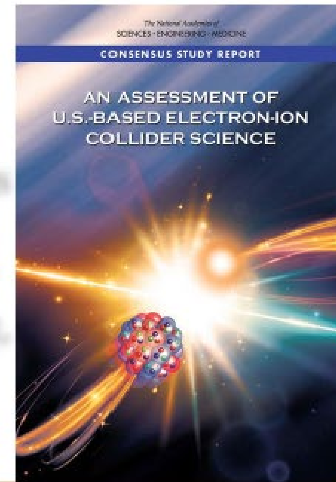
2012 White paper



2015 NSAC Long Range Plan

2018 NAS report

"The committee finds that the science that can be addressed by an EIC is compelling, fundamental and timely."



2018 INT workshop

More surprises in the nucleon sea might await us….


THANK YOU
thanks
THANKS
Thanks
danke!
謝謝
Gracias
شكرا
THANKS
THANK
YOU
gracias
merci
THANK YOU
thanks